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WATER RESOURCES ACTIVITIES IN THE
UNITED STATES. SALINE WATER
CONVERSION

Select Committee on National Water Resources,
U. S. Senate

November 1959

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WATER RESOURCES ACTIVITIES
IN THE
UNITED STATES

SALINE WATER CONVERSION

SELECT COMMITTEE ON NATIONAL WATER RESOURCES
UNITED STATES SENATE

PURSUANT TO

S. Res. 48

EIGHTY-SIXTH CONGRESS

FIRST SESSION

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(Pursuant to S. Res. 48, 86th Cong.)

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(II)

STATEMENT BY THE CHAIRMAN

OCTOBER 25, 1959.

To the Members of the Select Committee on National Water Resources:

Among the other new technical methods and improved processes for increasing the usefulness of available water resources to which the Select Committee on National Water Resources is directed to give its attention under the provisions of Senate Resolution 48 is desalinization of saline and brackish waters. The search for processes to accomplish this have taxed the ingenuity of man for many centuries and practical methods for desalinization of ocean water in small quantities have been in use on ships for over 100 years. More recently, large-scale plants have been constructed and are in use in areas lacking in fresh water resources.

The Congress has long realized the value of the resource that would be ours if a means of converting the saline waters of the ocean at economical costs could be found. In 1952 the Department of the Interior was authorized and directed to sponsor a program of research in this field. The program was enlarged by the Congress in 1955 and just last year Congress authorized the construction of demonstration plants in an effort to speed up the Department's program toward achieving economical conversion of saline and brackish waters. This program is just getting underway and processes and sites for three demonstration plants have been selected.

Many hearings on, and reviews of, the Department's program have been conducted by both Houses of Congress in the past few years and a great bulk of information is available in the printed hearings and reports resulting from these studies.

As a means of summarizing and bringing up to date information on recent progress in this field I asked the Department of the Interior to prepare a report on an evaluation of recent efforts in the field of desalinization of brackish and ocean waters. In addition, a request was made of the Atomic Energy Commission for report on the most recent developments in the field of application of nuclear energy for desalinization purposes by means of combining nuclear reactors for the production of electric energy with desalinization plants, since this appears to be one of the most promising areas for developing an economical process.

The report prepared by the Department in response to my request will be of value in providing the committee with brief summary of recent progress in the field of desalinization and some indication of what might be expected in the future. Therefore, I am having it printed as one of our committee prints to furnish background information for the Members of the Senate and others interested in finding solutions to the Nation's water resources problems. The report by the Atomic Energy Commission on the application of nuclear energy for desalinization purposes will be included in Committee Print No. 27.

ROB'T S. KERR,
*Chairman, Select Committee on
National Water Resources.*

(III)

Excess of illustrations in
this document may be better
fitted on microfiche.

COMMUNICATIONS

JULY 23, 1959.

HON. FRED A. SEATON,
*The Secretary of the Interior,
Department of the Interior,
Washington, D.C.*

(Attention of Dr. Arthur L. Miller, Director, Office of Saline Water.)

MY DEAR MR. SECRETARY: Further reference is made to my letter of June 15, concerning the work of the Select Committee on National Water Resources. Among other aspects of the water resources field to which the attention of the committee is to be directed is the desalinization of saline and brackish waters. The committee believes that the Office of Saline Water is well equipped to provide the committee with necessary background in this field. Accordingly, it is requested that a report on the prospects for development of water supplies in the United States through desalinization of brackish and ocean water be prepared for the committee by the Office of Saline Water.

Principal objective of the report is to furnish background for the committee for use in considering steps that might be taken to encourage developments in this field. The report should contain a brief description of desalinization processes now in use, both here and abroad, discussing engineering principles, costs per thousand gallons and per acre-foot, and environmental conditions and actual areas within the United States suited to application of these processes. Similar information should be included on the processes now in the pilot plant stage with an evaluation of additional development time needed and prospects for further cost reduction through improvements resulting from pilot plant operations. In addition to the processes now in use or in the pilot plant stage, there should be a brief description of other types of desalting processes indicated by laboratory experiments or theoretical design to be feasible, with a brief description of the engineering principles involved, and the type of further investigations or development needed to determine practicality of the process and the possible geographical area of application of each process.

In conclusion, we would like to have your best estimate of to what extent desalinization will be practiced by 1980, giving geographical areas and amounts of water that can be produced at various cost levels. Also, the committee would like to have discussion of the relation of publicly supported and private work in development of desalting techniques and any other comments and suggestions which the Office of Saline Water would like to make relative to desalinization techniques and problems.

The committee has also requested the Atomic Energy Commission for a report on the most recent developments in the field of application of nuclear energy for desalinization purposes.

We would like this subject to be covered in a summary report of not more than 10,000 words with whatever charts, tables, appendixes, and graphic illustrations as may be considered necessary. It would be most helpful if this information could be furnished the committee by October 15, 1959.

The committee staff will be glad to discuss any problems which may arise in the preparation of the report with representatives of the Office of Saline Water.

Sincerely yours,

ROBT. S. KERR, *Chairman.*

U.S. DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington, D.C., October 19, 1959.

DEAR SENATOR KERR: We are pleased to respond to the request of the Senate Select Committee on National Water Resources for information on the prospects for developing water supplies in the United States through desalinization of brackish and ocean water.

Progress in the field of lower cost conversion or desalting of saline waters has been such that we can state that the prospects are excellent.

Congress established the Office of Saline Water for the express purpose of conserving and increasing the water resources of the Nation. Specifically, to provide for the development of practicable low-cost means of producing from sea water, or from other saline waters, water of a quality suitable for agriculture, industrial, municipal, and other beneficial consumptive uses.

Successful achievement of the goals of the Office of Saline Water may have far-reaching effects on our general economy, the health and happiness of our citizens, and the future well-being of this Nation. Secretary of the Interior Fred A. Seaton has predicted that the availability of water—just plain, ordinary water—may be our No. 1 domestic problem as early as 1975.

The facts indicate the accuracy of his conclusion.

The U.S. Geological Survey, whose studies of the availability and use of water are the most comprehensive in the world, has predicted that our demand for fresh water will more than double in the next two decades, soaring from our present heavy demand of approximately 250 billion gallons per day to an estimated 597 billion gallons per day by 1980. Our present rate of use is placing a heavy burden on available water supplies. In 1957, for example, moderate drought conditions in this country forced 15 percent of our population to endure curtailed or restricted use of water. If today's rate of demand can create such a situation, imagine the scope of the problem in 20 years when the water demands of an additional 100 million citizens will exceed readily available supplies.

In essence, the water problem is this: How do we supply a growing population and a dynamic economy with increasing amounts of water of adequate quality at reasonable cost?

We are sure that the committee is fully cognizant of programs that are authorized and in operation striving to conserve and develop our available water: Construction of dams and reservoirs by the Bureau of Reclamation and the Corps of Engineers; conservation practices and programs of this Department and the Department of Agriculture; pollution control; evaporation suppression; industrial re-use of water; weather control; cloud seeding; etc. All of these programs are making important contributions to the proper development and utilization of our available fresh water supplies. The saline water conversion program is the only program that is not limited by the fact that there is only a fixed amount of fresh water available. In spite of every concerted effort to obtain maximum utilization of these supplies, additional sources of water will be needed to meet the predicted demands of the coming decades.

Clearly, then, we are forced to reach the conclusion that we must develop a new source of supply. This is the goal of the Office of Saline Water.

Fortunately, there is no shortage of water. Three-fifths of the globe is covered by oceans that contain an estimated 320 million cubic miles of water. In addition to this inexhaustible potential source of supply there are billions of gallons of presently unusable surface and underground brackish waters.

Processes must be developed that will permit us to economically convert these reserves into good, usable, potable supplies of fresh water.

In the 7 years the Office of Saline Water has been in existence considerable progress toward the achievement of this goal can be noted. In spite of rising cost indices, the cost of converting sea and brackish water to fresh is coming down. Just prior to World War II the cost of converting sea water to fresh ranged upward from \$4 per thousand gallons. In one or more of the plants Public Law 85-883 authorizes the Department to construct and operate, we expect to convert saline water to fresh for less than \$1 per thousand gallons.

Substantial as this progress may be, we would like to point out to the committee that some of the processes to be tested under the provisions of Public Law 85-883 are completely new. The plants in which they are incorporated will be the first of a kind. The experience gained from operating these plants will undoubtedly lead to improvements that will further lower the cost of conversion. New processes, still in the laboratory stage and not advanced far enough to be considered for demonstration plant programing, give promise of lowering the cost of conversion below 50 cents per thousand gallons.

While these cost figures may seem relatively high, it is important to note that in computing the cost of converted water we consider all costs. There are no charge-offs, no subsidies. In comparing these costs with the cost of natural water care must be exercised to use similar yardsticks to measure value.

Cost of present water supplies should not be compared with conversion costs, but rather the cost of developing additional water supplies to meet future needs—if indeed additional supplies are available.

Secretary Seaton has appointed an advisory committee to evaluate the progress of the Office of Saline Water and make recommendations on future activities. At their last meeting, in March 1958, the committee submitted the following recommendations:

1. Program should be accelerated through stepped-up appropriations making full use of the existing authorization.

(The appropriation for fiscal year 1960 was \$1,755,000 which is \$400,000 more than the pro rata share of the existing authorization.)

2. Existing authorization should be spent for research and initial pilot plant development.

(Public Law 85-883 has permitted us to schedule large pilot plants under a new authorization, thereby allowing funds appropriated under the initial authorization for research and pilot plant development as recommended.)

3. Large pilot plants should come from additional authorization and earmarked appropriations which are recommended.

(Public Law 85-883 is in line with this recommendation.)

4. The duration of the saline water program should be extended beyond the existing authorization.

(The present research and development program of the Office of Saline Water is authorized only through fiscal year 1963. The Senate select committee may want to carefully consider extending the present authorization as suggested by this recommendation.)

5. We should foster foreign contacts and have at least one research project outside the United States which would serve to encourage others.

(Several foreign countries are actively engaged in saline water conversion research. We exchange information with many of these countries, but we do not have sufficient funds to carry out many worthy research projects proposed by U.S. scientists and, therefore, have had to deny proposed research projects outside the United States. Although the plan proposed in this recommendation is highly desirable, under our present appropriations, we cannot apportion the necessary funds to foster this work.)

6. We should encourage cooperating in a foreign demonstration plant in exchange for technological information to the Office of Saline Water regardless of what Government agency would be involved.

(Lack of necessary funds has prevented the Office of Saline Water from initiating action under this recommendation and no other Government agency has sponsored such a program.)

7. Availability of a seaside test facility would be extremely desirable.

(It is possible that one of the sites selected for a demonstration plant may be developed to serve as a seaside test station for pilot plant activity.)

8. Basic and exploratory research must be continued.

(Basic and exploratory research is being continued at an accelerated pace, but unless present authorization is changed, this activity will be ended in 2 years.)

9. There is an urgency in California which requires definitive conclusions within 6 to 8 years relative to the California water plan.

(We are fully aware of the urgency of the water problem in California. We are sure the Senate select committee is also aware of this acute situation, but you may not be fully apprised of conditions in other areas of the Nation. We are deeply concerned over the number of cities and communities that asked to be considered as a site for one of the five demonstration plants authorized by Public Law 85-883. The applications did not come just from southern California and the arid areas of the Southwest. Over 175 applications have been received, from Alaska and Hawaii, from every State on our coastal perimeter except Delaware, and from 11 inland States the applications have poured in. Many of these cities have asked to be considered as a site for one of these five plants because they are desperate for additional supplies of fresh water and they have no natural source of supply to which they can turn.)

10. An increased effort should be made to inform the public of the program, progress, and responsibilities.

(We are making a concerted effort to accomplish the goal established by this recommendation.)

VII

A meeting of the advisory committee has been scheduled for December 3. We will advise the select committee of any recommendations suggested by the advisers at that meeting.

Considerable information on the saline water conversion program was presented by the Office of Saline Water to the House Committee on Government Operations in 1958. We are attaching a copy of the committee report which contains several recommendations designed to improve the saline water conversion program. Some of the recommendations of the House committee have been adopted and put into operation and others have not been initiated due to limited funds or lack of authorization.

For years the citizens of Coalinga, Calif., like many other communities in this country, have had to haul in their drinking water supplies. In Coalinga, this water was obtained at a cost of \$7 per thousand gallons. Earlier this year this community cut their water bill to \$1.45 per thousand gallons and made U.S. history by becoming the first to get its drinking water supply from brackish well water. Many other cities are considering a similar step, as evidenced by the number of cities bidding for one of the demonstration plants. During the next 20 years we fully expect many cities and communities to follow the lead established by Coalinga. By 1980 hundreds of cities and communities in many sections of the country will be obtaining all or at least part of their fresh water supplies from converted sea or brackish water. If the people of California fail to authorize the proposed \$1.75 billion bond issue to inaugurate the \$12 billion California water plan, which is a distinct possibility, widespread use of converted sea water can be expected in southern California in the immediate future.

The Office of Saline Water is successfully attracting the attention of more and more of our major industrial and research organizations to the unsolved technological problems of saline water conversion. New ideas and new proposals are being received by the Office in increasing numbers. Some of these have real merit and hold promise of lowering desalting costs. With the Office of Saline Water providing the leadership, with incentive furnished by our growing water problem, and with the technological know-how of American industry applied to the problem, who knows what tomorrow may bring? Research and development conducted by the Office of Saline Water has substantially reduced the cost of conversion in just 7 years. Improvements on existing processes as well as new processes that will result in lower conversion costs are the promise of tomorrow.

Continued research and development by the Office of Saline Water is important for the future of life on this planet; the implications in saline and brackish water conversion stagger the imagination. The arrival of one or more genuinely low-cost processes can well turn out to be one of the most important scientific achievements of our time.

At your request, we are sending the committee considerable information on the basic research process developments, and the demonstration plant programs of the Office of Saline Water, a brief description of conversion processes now in use or under development, cost estimates, charts, tables, and illustrations. Should you have need for additional information we would be pleased to receive your requests.

Sincerely yours,

FRED G. AANDAHIL,
Assistant Secretary of the Interior.

HON. ROBERT S. KEER,
*U.S. Senate,
Select Committee on National Water Resources,
Washington, D.C.*

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INTRODUCTION

SALINE WATER CONVERSION

The saline water conversion program now consists of three parts—fundamental research, process development, and demonstration—and certainly all three of these activities are essential to the ultimate solution of the problem. However, if an effective and dynamic program is to be maintained and accelerated it must be built on a solid foundation of progressive basic research. This type of research consists of extracting from nature the basic information and data needed for the development of new or improved conversion processes. Basic research is the solid foundation upon which the entire program stands. Without fundamental research all attempts to improve processes would be limited to making various modifications on existing processes on a trial-and-error basis. Any progress made under those conditions

would always be quite limited and the entire program might well collapse because of its weak foundation.

Low cost saline water conversion is a problem which has not been satisfactorily solved to date. New ideas and new processes are needed and can be achieved only through fundamental research. It is very unlikely that the conversion processes presently available for the demonstration plants are the best that can be developed. Further research can not only improve those processes but also holds promise of developing entirely new methods which may permit the attainment of a major breakthrough. Additional conversion methods are needed now for consideration in the demonstration plant activity.

PART I. FUNDAMENTAL RESEARCH

FUNDAMENTAL RESEARCH COMPLETED

Although fundamental research efforts in the past have been somewhat limited, good results have been obtained and new knowledge has been developed. The Office of Saline Water has completed a number of basic research investigations, a few of which are listed below:

1. *Minimum energy requirements for separation.*—This investigation demonstrated that the absolute minimum energy required to separate 1,000 gallons of fresh water from sea water is 2.8 kilowatt-hours, regardless of the type of conversion process used. That minimum requirement is for an ideal process (with no losses or inefficiencies) whereas for any practical process the minimum energy requirement would be around four times that value or approximately 12 kilowatt-hours per 1,000 gallons. These data have furnished a baseline or yardstick and have been very

useful in comparing the relative merits of the different conversion systems.

2. *Osmionisis.*—As a result of the theoretical research investigation above, a new approach to saline water conversion was suggested. In this process the driving force causing demineralization is produced by the concentration difference between brine and feed water and the term "osmionisis" was coined to describe the combination of osmotic and ionic forces existing between the two solutions. Subsequent research resulted in the development, on a laboratory scale, of a completely new conversion process.

In the simplest form of the apparatus two cation- and two anion-selective membranes form a three compartment cell, each chamber initially containing feed water, and the assembly is immersed in brine (fig. 1). The passage of ions from the brine to the less concentrated water in the outer chambers through the appropriate membranes is

FIGURE 1

LEGEND

-  = Cation permselective membrane
-  = Anion permselective membrane
-  = Inert and impervious material

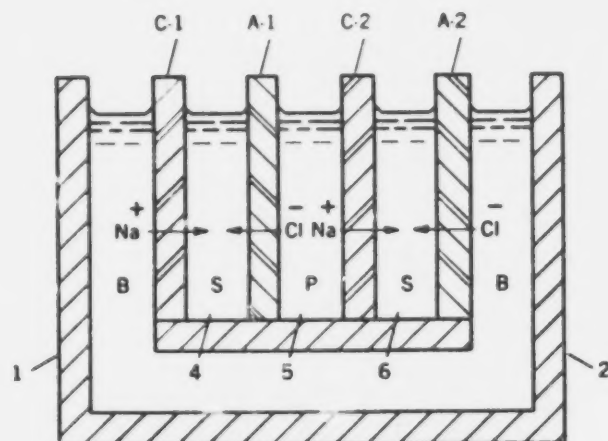
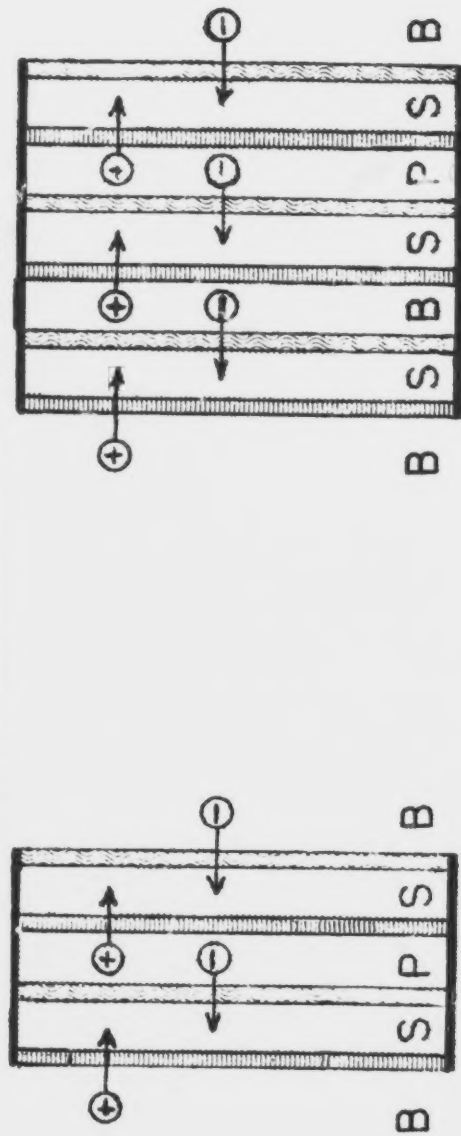


FIGURE II.—REPEATING MEMBRANE ARRANGEMENTS SINGLE TO MULTIPLE EFFECT



A. SINGLE EFFECT

B. DOUBLE EFFECT

KEY

- B = Brine
- P = Product Water
- S = Brackish Water



CATION MEMBRANE

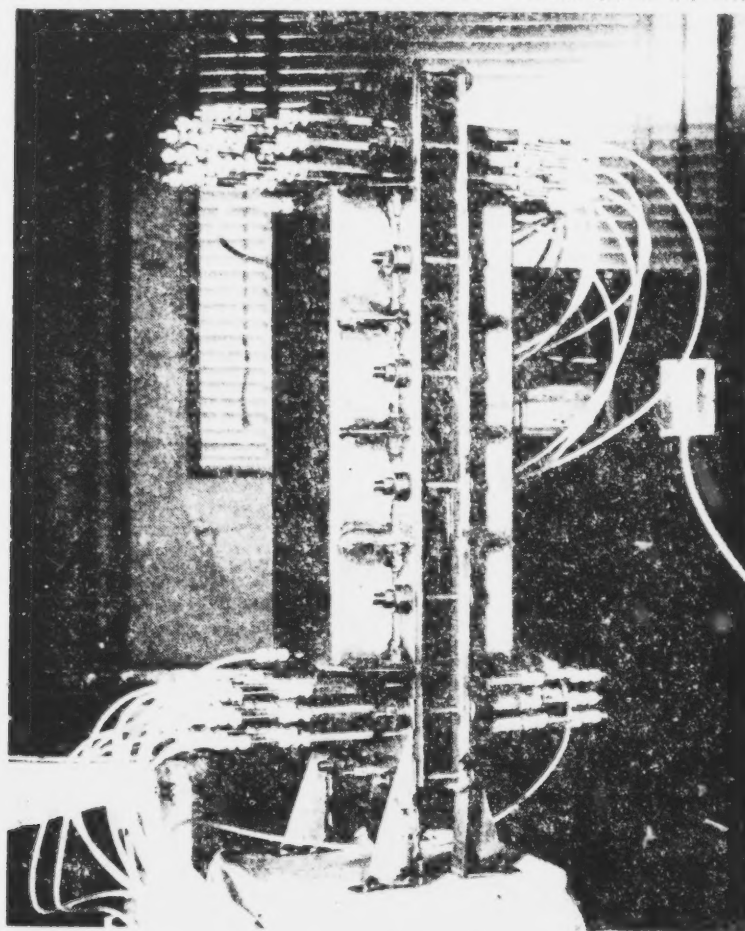
ANION MEMBRANE

necessarily electrostatically coupled with simultaneous transfer of ions from the center to the outer chambers. Hence, feed water in the center chamber is demineralized. Certain similar arrangements of three or more membrane pairs (illustrated in fig. II) lead to a multiplication of the

driving force, with resultant improvement in rapidly and degree of demineralization, but the principles are the same as for the simplest arrangement.

The laboratory prototype developed by Southern Research Institute is illustrated in figure III.

FIGURE III. OSMOGENESIS. LABORATORY PROTOTYPE BY SOUTHERN RESEARCH INSTITUTE

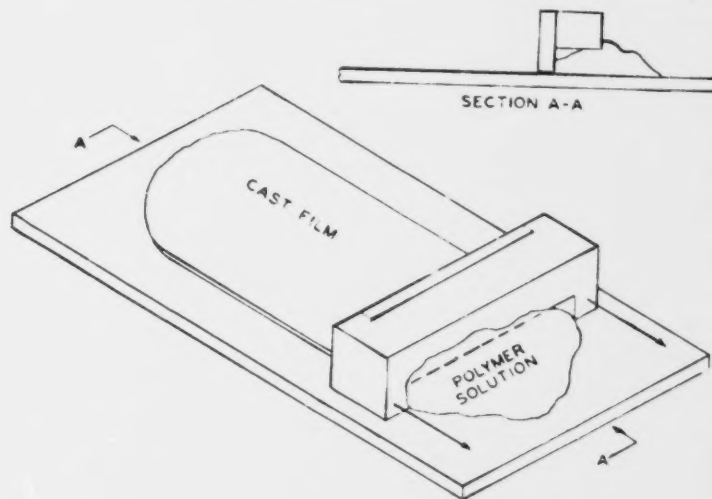


3. *Ion-selective and ion-restraining membranes.*—A. Membrane research is important because one of the limiting factors in the use of all membrane processes has been the membranes themselves. Fundamental research on ion-selective membranes has been directed toward the interpretation of membrane performance in terms of structure; the establishment of characterization parameters so that performance of a membrane can be predicted; and the preparation of improved membranes having high selectivity and low ohmic resistance. Greatly improved ion-selective mem-

branes have been developed as a result of research carried on by industry, Office of Saline Water, and other organizations.

One investigation sponsored by the Office of Saline Water was directed toward the preparation of the interpolymer membranes. These are made by a process which is simple and inexpensive, and which involves dissolving two fairly common plastics in the proper solvent, forming a film by spreading this solution out on a plate or on a rotating drum, and drying it (fig. IV A).

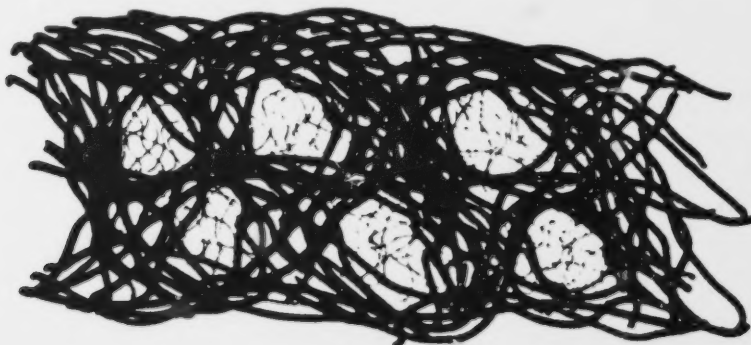
FIGURE IVa.—PREPARATION OF MEMBRANES BY "DOCTOR BLADE" TECHNIQUE



The films consist of an intimate intertwining of two long-chain molecules, one of which is water insoluble, tough, and flexible, and which serves as a matrix. The other is highly charged, water soluble, and provides the electrical conditions for ion-selectivity. Figure IV-B shows how the strands of the insoluble polymer (thicker lines)

intermesh and hold the active polymer. The matrix is usually a material commonly used in textile manufacture, such as nylon, orlon, or dynel. The interpolymer technique allows the preparation of membranes that have a wide range of physical characteristics and that contain a large number of different ionic groups.

FIGURE IVb.—INTERTWINING OF STRANDS OF INSOLUBLE POLYMER AND ACTIVE POLYMER TO FORM MEMBRANE



B. Fundamental research on ion-restraining membranes (osmotic or semipermeable membranes) has demonstrated that purification of sea or brackish water by reverse osmosis is technically feasible. This process operates on the well-known principle that if a solution is placed on one side of an osmotic membrane, and pure water on the other, water will diffuse from the pure water side through the membrane to the salt water side. This flow can be prevented by exerting a certain pressure, called osmotic pressure, on the salt water. If a

pressure higher than the osmotic pressure is exerted on the salt water, the flow will be reversed, and pure water will be removed through the membrane from the salt solution. For sea water the osmotic pressure is about 350 pounds per square inch; it is less for less saline waters. The low energy requirement calculated for this process makes it attractive. Some ion-restraining membranes tested have been able to reduce the salt content of water forced through them by 95 to 99 percent.

The principal criteria for judging ion-restraining membranes are (1) salt rejection, (2) flow rate, and (3) durability. To date, the limited durability of the membranes and their low flow rate have prevented the development of a practical reverse osmosis conversion process.

4. *Conditions affecting freezing of solutions.*—Fundamental studies have been completed on growth of ice crystals, means of increasing size of crystals, type of ice crystals formed under various conditions, means of removing brine from the crystals, etc. The results materially aided the development of methods for separating the ice from the brine in freezing conversion processes.

5. *Transport depletion.*—Research on this potential conversion process has indicated that it is technically feasible and additional study may be desirable. In its simplest form the process consists of zones or layers called controls (in which the transport number of ions are different from those in an aqueous solution) interposed across the path of ions moving through an aqueous solution under the influence of a potential gradient. The concentration of the ionic components of the solution will be increased on one side of each interposed layer and decreased on the other side (fig. V). Transport depletion is a variant of electrodialysis but differs from the latter in the nature of the layers or controls, and all the controls are of the same character.

CURRENT FUNDAMENTAL RESEARCH

1. *Scale deposition on heated surfaces.*—The formation of scale deposits in distillation equipment, and in some instances electrodialysis equipment, is a serious problem. It is important that methods for eliminating scale be developed. If scale cannot be eliminated or alleviated, the evaporative methods become inoperable or lose their efficiency due to the reduction in heat transfer rate. Consequently, fundamental research aimed at attaining a better understanding of scale formation and in developing means of alleviating or controlling it is being carried on.

The first phase of this study consisting of a review and critical evaluation of all available data on scale formation has been completed. The results indicated a great lack of quantitative data on the mechanism of scale deposition.

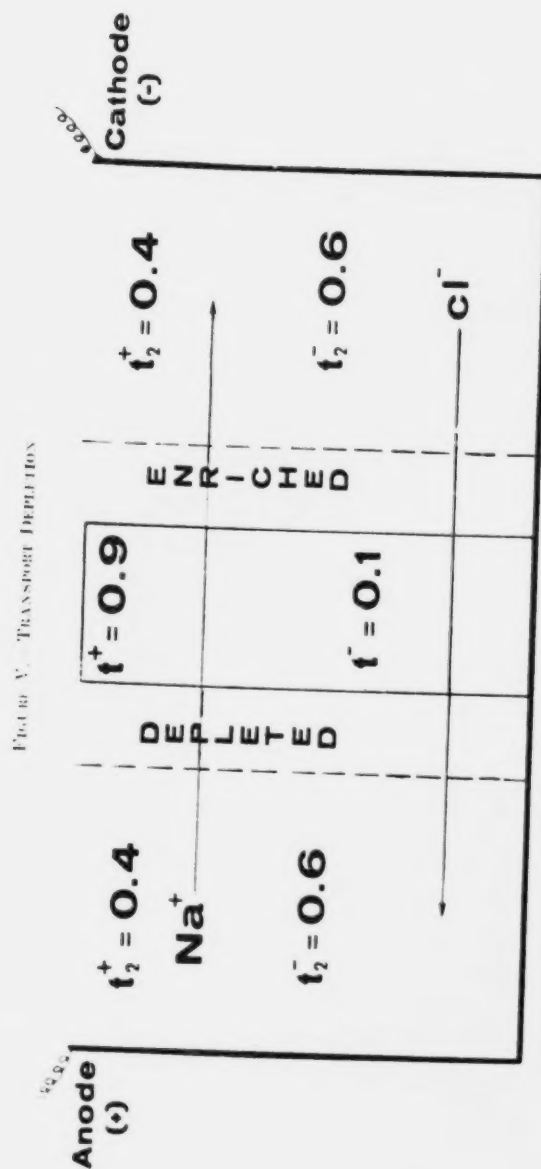
The second phase of this study, a laboratory investigation of the basic factors affecting scale deposition on heated surfaces, was initiated by the University of Michigan Research Institute. The first

part of this work involves studies with simple aqueous systems, including such items as the amount of supersaturation required before scaling occurs and the effect of such factors as velocity, temperature, surface, and presence of crystals on scale deposition. In addition, a theoretical study of temperature profiles and temperature gradients in a test section has been completed. Work is progressing satisfactorily and it is anticipated that the results eventually may permit the development of more economical means of scale prevention.

2. *Electrical control of adsorptivity.*—In essence the conversion process envisioned is based on the principle that a charge can be induced on a conductor, in contact with an electrolytic solution, by changing its electrical potential through an outside source. When charged, the surface of the electrode will attract (or adsorb) from the solution mobile ions of opposite sign. When the electric potential is reduced to zero, the adsorbed ions would be released to the solution. The first aim of this project was to prepare sheets of porous, inert, electrically conducting material which can function as electrodes in electrolytic solutions. Further aims are the determination of the ionic adsorptivity of these materials, and the effect of applied potentials thereon. It is believed that porous conducting materials will be found whose ionic adsorptivity can be controlled within wide limits by varying the potential (below the decomposition potential of water). This should lead to a conveniently controlled adsorption-desorption cycle for the demineralization of saline waters.

The soundness of the principle has been demonstrated and a rudimentary demineralization cell has been constructed and operated. On concentrations up to 0.01 normal saline solutions the cell gave fairly complete demineralization. The results indicate that electrically controlled adsorption-desorption gives a technically feasible demineralization process. However, several problems, such as the development of suitable anion-responsive electrodes and an increase in capacity of the electrodes, must be solved before the process becomes practicable.

3. *Use of algae.*—Certain algae are known to absorb and retain sodium chloride against high concentration gradients. Many investigators have concluded that the continued expenditure of metabolic energy by cells is necessary to maintain internal ion concentrations in excess of the environment. Thus a method for converting saline water was suggested and an exploratory investiga-



t_1^+ = transport No. of the cation within the control
 t_1^- = transport No. of the anion within the control
 t_2^+ = transport No. of cation within solution
 t_2^- = transport No. of anion within solution

tion was initiated. In essence, the theorized method would grow algae in a basin of sea water under conditions favorable for the uptake of salt by the algae. The algae would be mechanically separated from the water and removed to a second basin where conditions would be such that their metabolism would be inhibited. This might be achieved by the exclusion of light. If metabolic energy is denied to the organisms, they should secrete their internal sodium chloride in coming to equilibrium with the environment. It is believed that the algae would thus deposit the sodium chloride removed from the first basin into the second. Subsequently, the algae would again be mechanically separated from the water and returned to the first basin to pick up another load of salt. By a constant cycling process, the algae would gradually deplete the salt in the first basin. The water in the second basin would be constantly wasted after the algae had been removed. Several stages of this process utilizing algae native to progressively decreasing salinities could be operated in series to reduce the salinity of the product water to the desired level.

Over 100 different species of marine algae have been cultured to date and about 6 species have been found to accumulate sodium ions.

4. *Ion-selective membranes*.—Fundamental research on ion-selective membranes is continuing and includes work on the development of a sulfate-specific membrane, development of laboratory test procedures for characterizing membranes and the critical evaluation of all available ion-selective membranes.

This work is an integral and essential part of the overall program on processes utilizing ion-selective membranes. Electrodialysis is one of the leading methods for economical conversion of brackish waters and its present success is due primarily to the relatively recent development of highly selective, low resistance, ion-selective membranes.

5. *Solvent extraction*.—The possibility that fresh water might be extracted from saline water by means of certain organic liquids has been suggested and some exploratory research has been undertaken. Essentially, the liquid must be one that would absorb large quantities of water and at the same time be nearly insoluble in water.

A large number of commercially available compounds have been screened, new solvents have been synthesized, and phase equilibrium data have been obtained. Potentially valuable scientific data on

phase relations between saline waters and organic solvents have been obtained and the method has been shown to be technically feasible.

6. *Others*.—Small exploratory fundamental investigations are being carried on involving ion-retardation resins, chelation, and possible utilization of energy in the concentrated waste brines of conversion plants.

PROPOSED RESEARCH

Additional basic research is needed on properties of solutions, biological systems, hydration, adsorption, dropwise condensation, corrosion, polarization, transport depletion, ion exchange and other physical, chemical, and biological phenomena.

Exploratory research known to be needed at the present time amounts to over \$100,000 and undoubtedly additional meritorious proposals will be forthcoming during the year. Consequently, it is proposed to initiate work on all of the meritorious research investigations that can be supported by the funds allotted. These investigations may include, among others, the following:

1. *Gas hydrates*.—Essentially, a conversion process based on this principle would consist of contacting salt water with certain gases such as light hydrocarbons or halogenated methanes to form a solid hydrate. The mother liquor or brine is then separated from the crystalline hydrate; the latter is washed, and the fresh water is obtained by decomposing the solid hydrate.

This work will consist of a fundamental investigation of hydrate-forming agents. The research will include a study of the thermodynamic properties of several systems in order to determine which agents are most suitable from the standpoint of pressures, temperatures, and hydrate composition.

2. *Electrolytic system for conversion*.—The purification of saline and brackish waters by means of electrodialysis or by contact with ion-exchange resins is well known. Each of those systems, however, has inherent limitations. As a result of the recent development of new materials and techniques, a process consisting of a combination of electrodialysis and resin bed treatment may now be possible. It is believed that the inherent difficulties of both systems (electrodialysis and ion exchange) may now be minimized while retaining the virtues of each process. Essentially, this conversion process will utilize conductive ion-exchange materials which can be regenerated by

means of an electric current and ion-selective membranes to reduce the tendency of mixing the two solutions.

3. *Supersaturation in electrodialysis.*—As previously indicated, deposition of salts (scaling) is a problem in distillation equipment and under certain conditions in electrodialysis equipment. Although a basic investigation of salt deposition on heated metals is underway, the conditions experienced in evaporation methods and electrodialysis methods are so different that the data from one could hardly be expected to apply to the other. Thus, a study concerned with the prevention of precipitates during electrodialysis of brines or saline solutions is essential. Initially, conditions of supersaturation and precipitation of calcium sulfate at 25° C. (77° F.) will be studied. In addition, the use of external precipitators as a means of relieving supersaturation without creating deposits during the electrodialysis will also be studied.

If successful, maintenance of a supersaturated brine within electrodialysis equipment or external precipitation of supersaturated components might be possible. This would allow minimum brine stream volumes to be used in areas where brine disposal is restricted and would permit demineralization of water saturated in one or more major components which cannot be readily desalted by electrodialysis at this time.

4. *Ion-restraining membranes.*—As previously stated, several processes utilize membranes. The reverse osmosis process, from the standpoint of energy, looks quite attractive but its success depends on the development of a greatly improved ion-restraining (osmotic) membrane. New techniques for synthesizing membranes such as the electric discharge method for making ultrathin films and radiation methods for modifying preformed polymers have been proposed. The development of improved membranes for the reverse osmosis process initially will be limited to the synthesis and testing of ion-restraining membranes. For example, some of the avenues to be investigated may include (a) starch and protein membranes, (b) surface active membranes, (c) bound water membranes (such as suggested by the study at the University of Florida) and (d) air-gap membranes.

5. *Pressure-driven demineralization.* The objective of this proposed study would be to demonstrate a process for demineralizing water by using pressure as a driving force for ion transfer. Re-

verse osmosis has been shown to be technically feasible, and in this method the applied pressure drives the water through the membranes, leaving the salt ions behind. In contrast to reverse osmosis, it should be possible to demineralize water by using applied pressure to drive the dissolved ions through membranes permeable to them and impermeable to water. If a suitable membrane can be developed in which, unlike conventional ion-exchange membranes, it is permeable to both cations and anions, then the application of pressure should produce a means of recovering fresh water from saline water.

6. *Polarization.*—In electrodialysis the capacity of a given unit is proportional to the electric current applied to it. Because of limited transfer rates at the membrane-solution interface, a limiting "polarization" current is reached which dictates the capacity of the unit. Therefore, operating current densities (and capacities) must be set below the polarization value. Thus, the primary objective of this study would be to increase the capacity of electrodialysis equipment by increasing the limiting current density obtainable in such equipment. To achieve this objective the mechanism of polarization must be elucidated, especially the less-understood factors such as membrane-solution interactions and ionic species.

7. *Recycle de-ionization.*—The demineralization of saline water by ion exchange is known to be technically feasible. However, the cost of the regenerant chemicals required makes the process uneconomical for saline water conversion. If the regenerant chemicals can be recovered and reused, the economics of this process appear to be attractive.

Basically, recycle de-ionization would utilize a volatile salt, such as ammonium carbonate or bicarbonate, to regenerate a mixed bed ion-exchange system. Sea water would be passed through the mixed bed and the effluent would consist of water containing CO_2 and NH_3 . The carbon dioxide and ammonia would then be recovered by stripping or distilling and reused in regenerating the ion-exchange bed.

8. *Corrosion.*—Although a considerable amount of work has been done in evaluating materials for marine service, very little research has been completed on the behavior of metals in hot sea water. Corrosion may be a serious problem, particularly with distillation conversion processes which may be operated at relatively high temperatures, e.g., up to 350° F. Consequently, information on the

corrosion of metals exposed to hot sea water is essential.

9. *Effect of acoustic vibrations on heat transfer rates.*—It has been suggested that acoustic vibrations superposed on heat transfer surfaces may

offer a unique and inexpensive method for improving heat transfer rates and reducing scale formation in distillation units. If verified, this could reduce operating costs for distillation-type conversion units.

PART II. PROCESSES DEVELOPMENT

INTRODUCTION

The Processes Development Division develops through grants and contracts and by use of the facilities of existing Government laboratories, practical uses of scientific knowledge for application to the production of devices, systems, materials or processes, capable of converting saline water to fresh water at reasonable cost. Process engineering work performed includes advanced developmental investigations, working units, pilot plants, and field testing, cost estimates and designs with consideration of all economic factors. The Division has responsibility for translating research data and results of laboratory experiments and investigations into working units or pilot plants for converting saline water and for the development, testing, and operation of those units and evaluation of results.

The development of saline water conversion processes has advanced in a number of broad fields, each of which incorporates a number of different processes. These fields can be conveniently listed as follows: (1) distillation using fuels; (2) solar heat distillation; (3) membrane processes; (4) separation by freezing; and (5) other chemical, electrical, physical or other conversion methods, including solvent extraction and use of gas hydrates.

No one saline water conversion process is expected to be the complete answer for all uses. Different types of processes are advantageous for either of the two major divisions—sea water and brackish waters. In addition, other factors connected with location such as fuel costs, weather conditions and waste disposal conditions, can determine which of several processes would be the most economical to use. In looking to the future there is a further overall consideration of some processes being more likely to undergo further improvement through additional development than is the case with others. Finally, there are the possibilities of developing completely new processes through additional research which would result in even lower conversion costs than can be predicted at this time.

The distillation processes include several which are the furthest advanced today. Particularly, these are multiple-effect distillation with submerged tube type evaporators, multistage flash distillation and tubular vapor compression distillation. A fourth, which has recently advanced to the point where it has been selected for demonstration plant testing is the long-tube vertical multiple-effect distillation process (LTV) using special scale control techniques. Other distillation processes which show promise include rotary vapor compression, vapor compression tubular with forced circulation, single-stage flash utilizing naturally occurring temperature differences and, very recently, a vapor reheat multistage system, and a multiple-effect process using thin wiped-film methods with new fluted condensing surfaces.

The multiple-effect submerged tube and vapor compression distillation processes have been in commercial use for many years. More recently, the multistage flash process is becoming more prevalent, particularly for large multimillion gallon per day sea water conversion installations. Based upon their advanced developmental status and the possibilities of further improvement the LTV process and the multistage flash processes were selected for the first two sea water conversion demonstration plants of at least a million gallon per day capacity each.

Solar distillation has the advantage of eliminating the cost of fuel energy otherwise required. However, the research and development problems are difficult. Because of the diffuse nature of solar energy, ways must be found to build equipment at very low cost, of high efficiency, and low operation and maintenance costs in order to produce converted water at prices competitive with other types of distillation using fuels.

There are certain areas, particularly those of high solar intensity, where solar distillation may, in the future, provide the best means for conversion. Small commercial solar distillation units are now in operation in several foreign countries. More answers are being obtained through building and operating solar still prototypes of small pilot plants. Solar energy utilization in many areas,

including saline water conversion, could become increasingly important in the future.

There are a number of membrane processes which show promise of developing into economical means of converting saline water. The greatest area of application is the treatment of brackish water. However, future development in both membranes and equipment may also open up possibilities for their use on sea water.

Electrodialysis processes are the only membrane conversion processes which at this time have advanced beyond the research or laboratory stages of development. Commercial units are now available and a number are in use. Several brackish water plants with conversion capacities ranging up to 86,000 gallons per day are in commercial operation. A 2.5 million gallon per day plant is under construction in South Africa. There are several different electrodialysis processes depending upon the types and designs of equipment used.

Electrodialysis processes have become sufficiently developed for one to be selected for the first brackish water conversion demonstration plant of about 250,000 gallon per day capacity. Electrodialysis, particularly since it is new, is expected to have substantial improvements and cost reductions through additional research and development. Other membrane processes such as reverse osmosis and osmionisis may likewise develop into future commercial use.

The development of freezing processes is very new. They have certain inherent advantages which in the future should make them more than competitive with the better distillation processes. However, they are only now reaching pilot plant stages of development. The two more promising approaches are both direct freezing processes, one in which the water vapor itself serves as a refrigerant and the second wherein a secondary refrigerant such as butane is used. A 15,000-gallon-per-day pilot plant incorporating the first process is now being completed. There has been recent increased interest in the possibilities of freezing for conversion by both Government and industry.

In the category of other processes, the one furthest advanced in the laboratory is that of solvent extraction. Additional development will give answers as to its future economic potential. Its most promising area of application would be to treat brackish waters in the 5,000 to 10,000 parts per million dissolved solids range. A newer conversion process possibility now becoming of greater interest, and on which laboratory work has

been carried out, is use of gas hydrates; that is, where a hydrocarbon gas such as propane is used to form hydrate crystals from which the desalted water can be recovered.

In the overall view of the saline water conversion field, one can now realize that there is a dynamic progressive program of research and development activity in a number of areas and a number of processes. Continued efforts in basic research, in the development of processes, in the operation of demonstration plants, and continued research on interrelated problems such as scale, corrosion, and improved heat transfer, can only result in better and lower cost conversion.

More detailed discussions of various processes follow.

DISTILLATION PROCESSES

Distillation of sea water has been practiced for many years and has found major applications in industry and in the military services. In recent years large land base installations built in areas where fresh water was at a premium have been producing millions of gallons per day of fresh water from the sea. Examples of such installations are at Kuwait, Aruba, and Curacao.

Generally speaking, those types of applications did not have costs of the water produced as a primary consideration. Since the initiation of the saline water conversion program more and more attention has been given to the development of improved distillation processes with the major objective of reducing conversion costs for large-scale production for possible industrial and municipal uses.

Research has been carried out to improve the many phases of distillation and to solve major technological problems such as scale formation, and corrosion.

The long-tube vertical multiple-effect distillation process incorporates a new method of scale control known as sludge recirculation. This process will receive its first major test in the sea water conversion demonstration plant which will be built at Freeport, Tex. The plant will have a designed capacity of a million gallons per day.

In recent years, there have been important commercial developments in multistage flash distillation, both in application for marine uses and large land base plants. Those developments together with results of design studies sponsored by the Office of Saline Water which included possible combination with nuclear process steam reactors

led to the selection on May 14 of this process for the second sea water conversion plant. It will also be designed to produce a million gallons of fresh water per day.

Thus, there are now distillation processes feasible for multimillion gallons per day conversion plants. While these plants will represent the most promising of the presently known processes, continued research and development will undoubtedly render them obsolete by leading to more efficient, lower cost distillation methods. For example, research is continuing on the long-tube vertical pilot installation which may result in yet another major improvement in that system. There are new approaches to be investigated such as the vapor reheat cycle. A promising forced-circulation, vapor-compression cycle will soon be advanced from the laboratory to pilot plant operation and additional research on scale and corrosion problems may provide improvements of major importance.

Progress in conversion cost reduction by means of distillation has been made and will continue.

Just prior to World War II the cost of producing a thousand gallons of fresh water from sea water by distillation ranged upward from \$4. Since then, the rising cost indice has sharply advanced all dollar costs. In spite of this trend, the cost of sea water conversion has been substantially reduced. The cost of fresh water produced by the most efficient existing sea water conversion plants is now about \$1.75 per thousand gallons. It is anticipated that the first two sea water distillation demonstration plants will produce fresh water from the sea for \$1 or less per thousand gallons.

1. *Multiple-effect long-tube vertical evaporator.*—The system of multiple-effect evaporation wherein the vapor produced in one evaporator in a series is used as the heat source for the next evaporator operating at a lower temperature and pressure, has been applied for many years to the evaporation of sea water. The long-tube vertical evaporator may be one of the most economical methods for sea water conversion providing scale and corrosion can be controlled.

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FIGURE 1. LONG TUBE VERTICAL EVAPORATOR

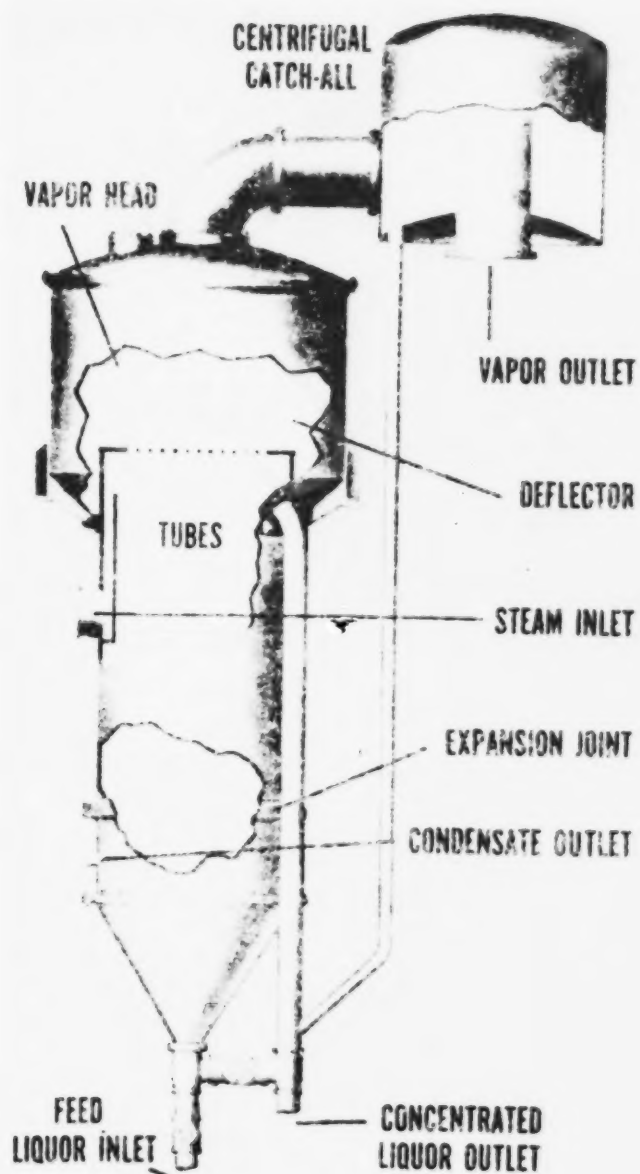
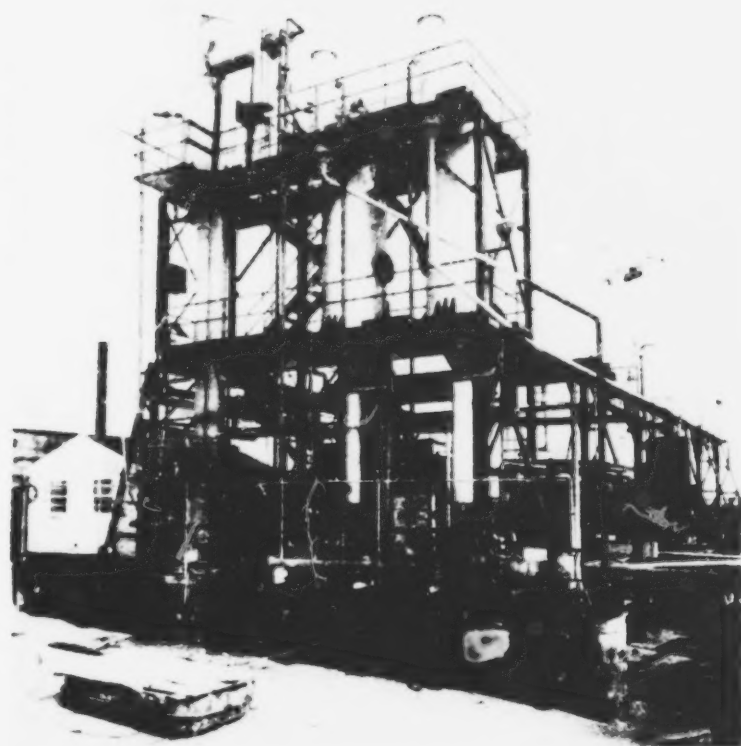


FIGURE II. LONG-TUBE VERTICAL EVAPORATOR AT HARBOR ISLAND.

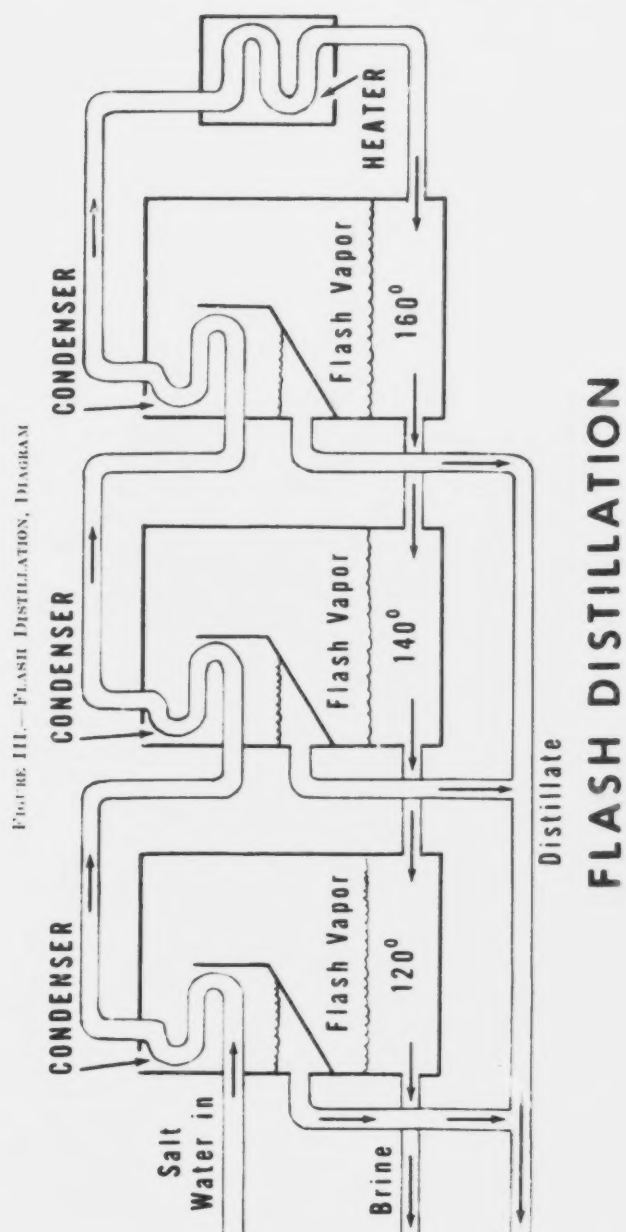


The long tube vertical evaporator is a vertical nest of tubes with heating steam on the outside and the liquor on the inside (fig. I). Development of its application to sea water conversion has been carried on by contracts with Whiting Co. and W. L. Badger & Associates at the International Nickel Co.'s corrosion laboratory at Harbor Island, N.C. (fig. II). It has been shown by experiments that falling film operation, that is, with the feed flowing down the tubes from the top, gives higher heat transfer coefficients and consequently more economical operation. In this type of evaporator, scale is a major problem and a method has been worked out to control scale by adding salt crystals to the raw sea water. The theory is that the scale forming salts, which are on the verge of precipitation from the mother liquor, will deposit on its own kind rather than on a foreign surface, such as the walls of the evaporator tubes. By recirculating the sludge this method of control becomes self-perpetuating in a multi-effect plant; no chemicals are required for the process other than for the initiation of the process. Experiments now indicate that mild steel can be used in a number

of the evaporator effects. Thus, two major premises for the cheap production of fresh water from sea water have been verified, and will be incorporated into the first demonstration plant of the Office of Saline Water.

2. *Flash distillation.* Figure III shows a simplified diagram of a flash distillation process. In flash distillation, sea water is progressively heated and then introduced into a large chamber where a pressure just below the boiling point of the hot brine is maintained. When the brine enters this chamber the reduced pressure causes part of the liquid to immediately boil, or flash, into steam. The remaining brine is passed through a series of similar chambers (multistages) at successively higher vacuum where the flash process is repeated at progressively lower temperatures.

The progressive heating is accomplished by piping the incoming sea water through the flash chambers, starting at the low temperature end. In each chamber the flashed vapor condenses as it gives up its heat to the incoming sea water. The condensed vapor is the product water of the plant.



Final heating of the sea water before flashing takes place in a salt water heater.

The Office of Saline Water, by contract with the Fluor Corp., has sponsored design improvements on multistage flash distillation to effect greater economies involving a combination of a flash system with a nuclear reactor to supply the energy. However, almost all commercial flash processes have been limited to temperatures below 180° F. If higher temperature operation can be achieved through research and pilot plant development, greater economies will be realized for saline water conversion. Thus, the Office of Saline Water plans to sponsor research and development work in flash distillation at the higher temperatures.

3. *Forced-circulation vapor compression stills.*—The economic evaluation of saline water conversion by means of forced-circulation vapor-compression distillation was performed under a contract with Dodge and Eshaya of Yale University. The objective of the contract was to determine whether further work on the forced-circulation and dropwise condensation vapor-compression evaporator is desirable. This process is a vapor-compression cycle in which the brine is in forced circulation within the tubes and the compressed steam condenses in droplets, rather than a thin film, on the outside of the tubes. Theoretical evidence supports the view that dropwise condensation and forced circulation will result in increasing the overall heat-transfer coefficient in industrial distillation equipment by a factor of three to four over coefficients in present-day equipment while forced circulation is expected to bring about an additional improvement by controlling or retarding and eliminating the formation of scale. The Office of Saline Water has plans to continue its experimental and development work with the forced-circulation vapor-compression systems.

4. *The Hickman rotary still.*—Several years ago, Dr. Kenneth Hickman of Rochester, N.Y., invented a distillation unit which employed a rotating disk as the heat transfer surface. This rotating surface furnished heat transfer coefficients from four to six times greater than previously obtained in any other type of distillation equipment. Consequently, a small still was designed and built to determine whether these high transfer (coefficients $U=3,500$ or better) could be maintained on a prolonged operation on full-strength sea water. The experimental work showed that these coefficients were achieved and two larger units were sub-

sequently designed and built by Badger Manufacturing Co. to determine the feasibility of larger units (fig. IV). The larger stills, for yet undetermined reasons, did not produce the same heat transfer coefficients. Other problems associated with larger units were also encountered, clearly demonstrating the need of additional research before further development could proceed. A contract was negotiated with Battelle Memorial Institute to explore fully the parameters affecting the distillation of sea water from a rotating surface, as well as to determine the economic advantages of the Hickman process.

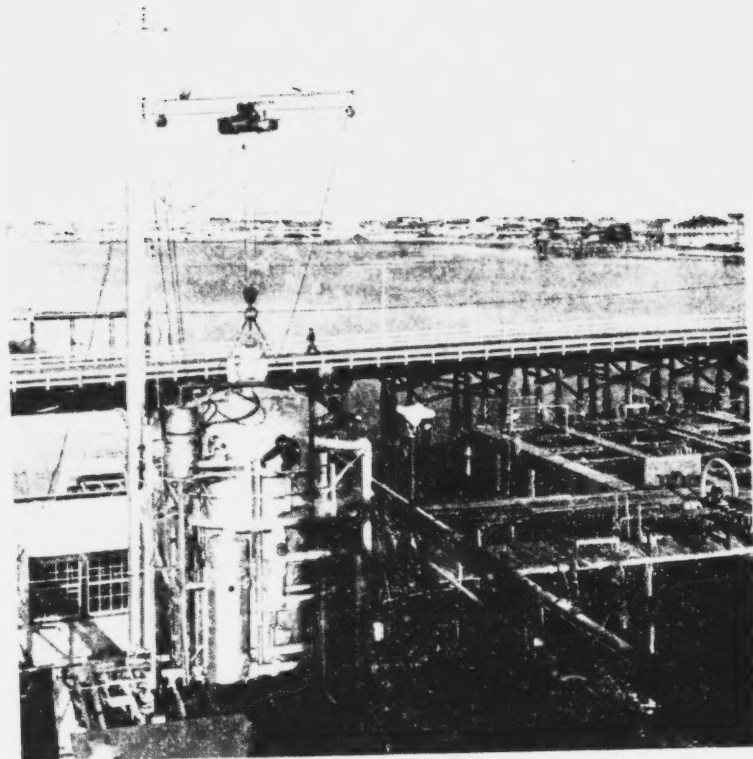
In addition to the Hickman still, the Office of Saline Water is investigating at the Bureau of Reclamation Laboratories in Denver, Colo., the merits of another rotary distillation method known as the Glaxo still. In this unit, it is proposed to incorporate the compressor into the spinning heat transfer surface in order to eliminate the need for a separate compressor. This should bring about a simplification of rotary type stills which will further reduce the cost of converting saline water.

5. *Vapor reheat.*—In recent years, progress has been reported in the field of spray drying. Much remains to be learned, however, on the transfer of heat and mass to spray droplets, or more generally to fluids dispersed into sheets and various shapes by contact tower packing.

The elimination of solid heat transfer surfaces in a flash evaporator cycle would not only reduce or at least modify the scaling problem (which is particularly important because of increased economy by operating at a higher initial flash temperature, where scaling becomes more severe) but would save the high cost of metallic tubes or other surfaces. In the vapor reheat process preheated sea water flashes in stages to vapor and brine at a lower temperature and pressure just as in the standard multistage process. However, in this case the vapor condenses directly on sprays of product condensate pumped from the next lower condenser stage. The product condensate thus increases stepwise in temperature, pressure, and total amount from the last stage to the first stage.

A five-stage demonstration vapor reheat unit made of large glass flasks has been assembled under the direction of Dr. Donald F. Othmer at the Polytechnic Institute of Brooklyn, and should be ready for operation at this writing.

FIGURE IV. ROTARY VAPOR COMPRESSION STILL AT HARBOR ISLAND



FREEZING PROCESSES

The purification of sea water by freezing is based on the observation that ice frozen from salt solution, washed free of salt and then melted, is fresh water. Unfortunately, washing the ice free of salt has been difficult to achieve because of the entrainment of brine or mother liquor within the interstices of the ice crystals. The problem of separation has been resolved in part by the development of more efficient countercurrent washing methods. Among the more promising approaches in this regard are controlled crystallization in which the size of the ice crystals is increased, and multistage washing in which the mother liquor is first displaced by solutions of lower salt concentration and finally by pure water. The inherent advantages of the freezing process such as low energy requirements, less tendency for scaling and

corrosion and possibility of operating at low temperature differentials, indicate that the method, when completely developed, will compete economically with existing distillation processes.

Although considerable progress has been made, further development of the technology of freezing remains to be accomplished. To date, no large-scale production operations have been reported. However, increasing interest in the process is reflected in reports from abroad. Especially noteworthy is the report from the Japanese Government Chemical Industrial Research Institute describing the successful operation of a 50,000 gallon per day capacity pilot plant designed to concentrate sea water and use the resulting brine for the production of salt.

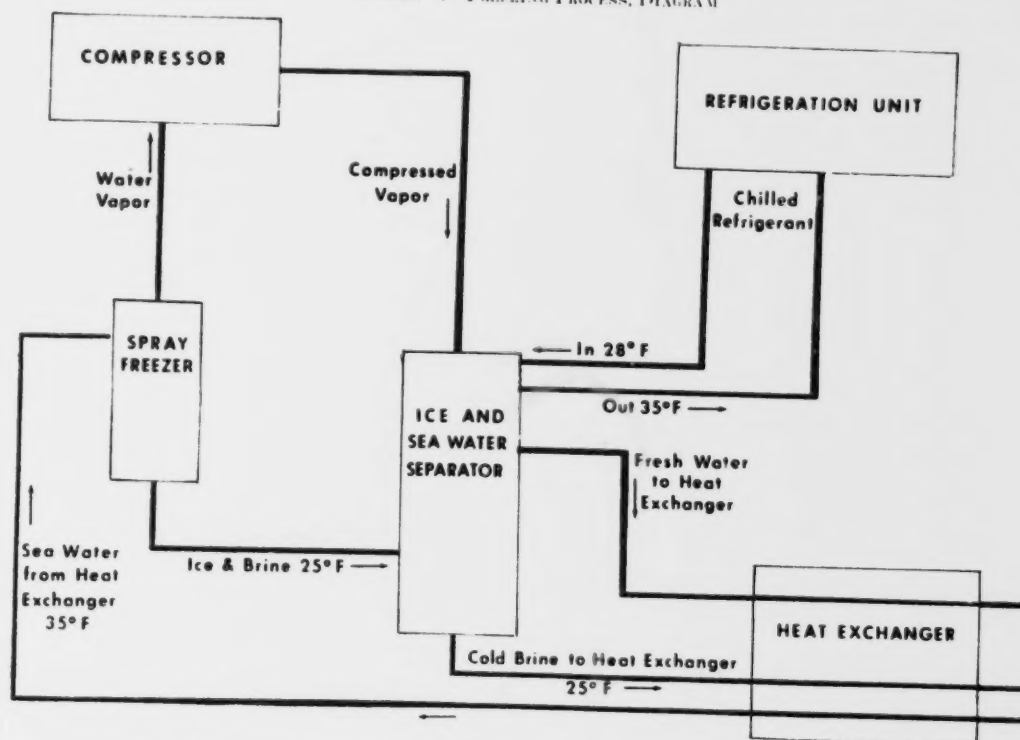
The application of the freeze-separation process is well suited to the coastal areas of the United States where fresh sea water of 35,000 parts per

million salts can be economically processed to potable water of 500 parts per million or less. Present conversion costs are estimated to be in the neighborhood of \$1 per 1,000 gallons, and it is hoped that with further advances in the technology of freezing, fresh water production may reach a cost of \$0.60 to 0.70 per 1,000 gallons. Conclusions as to the technical and economic feasibility

of the process must await the results of more extensive pilot plant evaluations.

1. *Direct freezing process.*—One of the more promising freezing methods investigated under contract is that developed by the Carrier Corp. which utilizes flash evaporation of precooled sea water to produce ice and countercurrent washing to separate the ice-brine mixture. The refrigeration

FIGURE V.—FREEZING PROCESS, DIAGRAM



FREEZE-EVAPORATION PROCESS

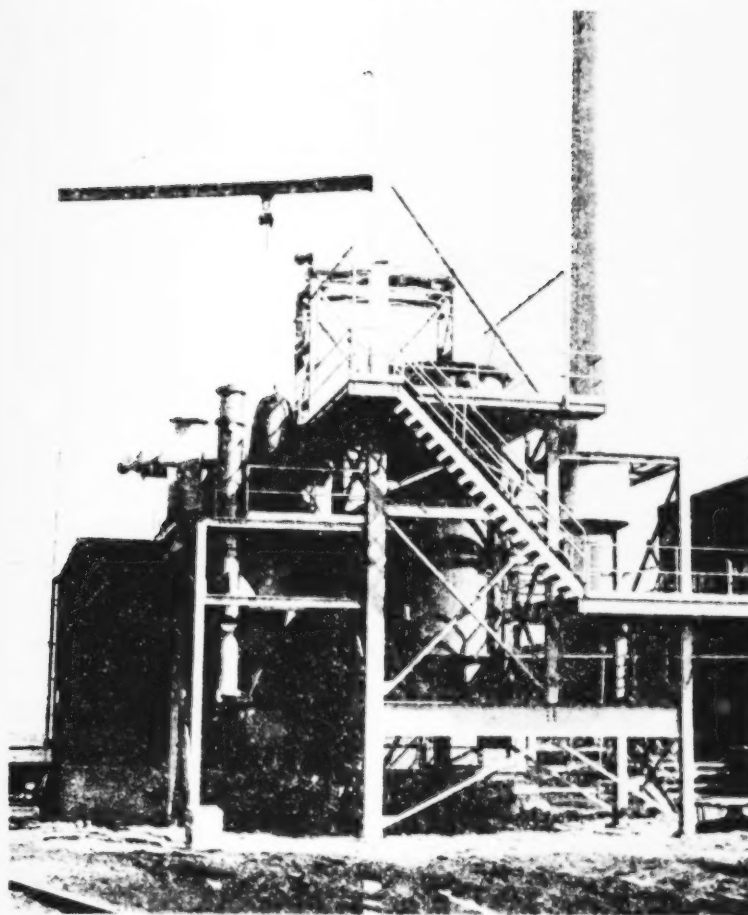
tion cycle is completed by mechanical compression or chemical absorption of the water vapor, or a combination of both (fig. V). In small pilot units continuous production at rates of 50 to 100 pounds of ice per hour has been realized.

In order to obtain a more valid technical and economic appraisal of the process, the Carrier Corp. has designed and built a pilot plant of 15,000 gallons per day capacity at the Carrier facility in Syracuse, N.Y. (fig. VI). Following preliminary testing and evaluation, the pilot plant will be disassembled and relocated at a seashore site for continuous operation. This phase of the program will permit the necessary experimental work for

obtaining data on optimum conditions of operation, maximum production capacities, and additional economies which can be extrapolated to large-scale production units.

2. *Direct freezing use of secondary refrigerant.*—Another freezing process utilizes an immiscible refrigerant in direct contact with precooled sea water. The flash evaporation of a refrigerant precludes the handling of large volumes of water vapor at low pressures. The poor efficiencies characteristic of low-pressure pumping systems are thus overcome. Hydrocarbon refrigerants such as butane and isobutane appear to meet the requirements of ice production at 24° F. The

FIGURE VI. DIRECT FREEZING PILOT PLANT, SYRACUSE



refrigerant vapor is compressed and the heat of compression is utilized to melt the ice after the latter has been washed free of salt by countercurrent washing. This process is now under development at Cornell University by Prof. H. F. Wiegandt. Because of the potential economies of using a direct contact refrigerant, the Cornell process is being considered for more extensive evaluation in a pilot plant of 2,000 gallons per day capacity.

3. *Zone freezing.*—The adaptation of zone freezing to the desalination of water has undergone preliminary investigation by Battelle Memorial Institute. The process, used extensively in the purification of high melting metals and intermetallic compounds, is based on the principle of purification by recrystallization. In other words, purification depends on the difference between the

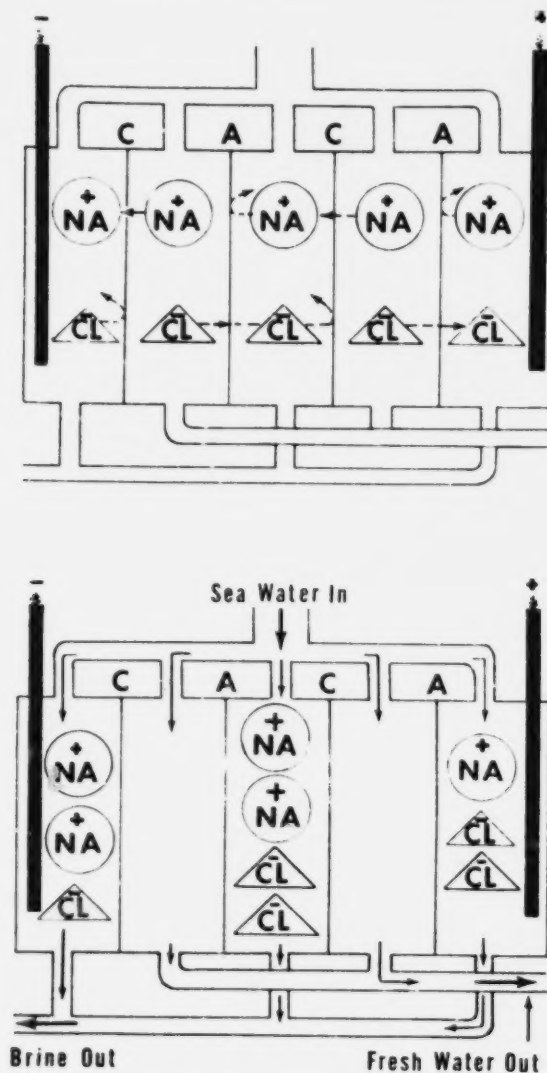
solubilities of a given impurity in the liquid and solid phases of the host material. The results of initial studies demonstrated technical feasibility but also indicated that salt water purified in this manner would cost in the range of \$3 to \$7 per 1,000 gallons. This estimate was based on the extrapolation of existing research data which was not directly applicable to an optimized process. Battelle is presently making a preliminary engineering evaluation of the process and, on the basis of small-scale experiments, will explore possible improvements in process design that may ultimately bring the zone freezing process into a more attractive cost range. In view of the present status of zone freezing, it would be difficult to predict its potential value to the saline water conversion program.

MEMBRANE PROCESSES

There are a number of potentially attractive conversion processes utilizing membranes. Several are now known to be technically feasible and one, electrodialysis, is economically feasible for the treatment of brackish water under certain conditions.

The membrane processes showing promise for the purification of brackish waters consist of (1) electrodialysis where an electromotive force is applied to a cell consisting of ion selective membranes; (2) "osmionic" where the concentration gradient between the solutions supplies the potential to drive ions through ion selective membranes; and (3) reverse osmosis where sufficient pressure

FIGURE VII.—ELECTRODIALYSIS CELL, DIAGRAM

**ELECTRO-DIALYSIS**

C-CATION PERMEABLE MEMBRANE
A-ANION PERMEABLE MEMBRANE

is applied to the solution to force water through an ion restraining membrane into the fresh water side.

In the electrodialysis process, use is made of the property of certain plastic membranes to pass only electrically positive particles (cations) and other membranes to pass only electrically negative particles (anions). When salts are dissolved in water they break up into equal quantities of cations and anions which move in opposite directions in an electrical field. An electrodialysis cell consists of alternate cation and anion permeable membranes (fig. VII). Upon the application of an electromotive force the positive ions, such as sodium, pass through the cation permeable membranes, whereas the negative ions, such as chloride, move in the opposite direction and pass through the anion permeable membranes. Thus, the water passing between alternate membrane pairs is depleted of salt, while that passing through the intervening pairs is enriched.

Since 1952, electrodialysis has developed from a laboratory phenomenon to the point where it is now one of the leading processes for demineralization of brackish waters. The Office of Saline Water has been active in developments since 1953. Extensive testing and evaluation of experimental electrodialysis equipment has been carried out. At the present time a general program of research and development is under way at the Bureau of Reclamation Laboratories, Denver, Colo.

One of the limiting factors in the use of electrodialysis has been the membranes themselves. During the past few years, improved ion-selective membranes have been developed by a number of organizations in several countries. If cost of membranes and equipment can be sufficiently reduced an electrodialysis process may also become economically feasible for demineralization of sea water.

Several electrodialysis plants with conversion capacities ranging up to 86,000 gallons per day are in commercial operation, with the largest plant at Bahrain, Persian Gulf. A 2.5 million gallons per day plant is under construction at Welkom, South Africa. Recently, Coalinga, a small community in California, became the first town in the United States to obtain its drinking water supply from converted brackish well water. By use of a small electrodialysis plant, they cut the cost of their water to about \$1.45 per thousand gallons as compared with the \$7 per thousand gallons it had cost to haul in their drinking water supplies.

Electrodialysis processes were considered sufficiently developed for one to be selected, on June

22, for the first brackish water conversion demonstration plant. The plant will be designed to convert brackish water into fresh at the rate of at least 250,000 gallons per day and will be located in the Northern Great Plains or the arid area of the Southwest. Depending on the initial salt content of the water to be treated, it is anticipated that the cost of the water from this plant will be in the range of 60 to 80 cents per thousand gallons. Since electrodialysis is, competitively speaking, in its infancy, continued research and development can be expected to lead to substantial improvements and cost reductions.

1. *Electrodialysis*.—The research and development conducted on the electrodialysis process began with laboratory studies at a time when the process was only beginning to emerge from the laboratory phase. As a result of this work, field tests were conducted in 1955 on a 25,000 gallons per day electrodialysis demineralizer operating respectively on 4,000 parts per million and 2,000 parts per million brackish well waters in Arizona and South Dakota. Results from these tests are contained in the Office of Saline Water Progress Report No. 11. Results of the field test showed: that electrical requirements were about 7 kilowatt-hours per thousand parts per million of salt removed, of which power for pumping was a substantial part; that the 3-year estimate for membrane life was probably reasonable; that the chemical composition of the water has a pronounced effect on unit operation, particularly in determining the quantity of waste brine flow; that current efficiencies remain high during extended operation indicating that no chemical deterioration of the resin in the membranes occurs; that scaling due to calcium carbonate and magnesium hydroxide precipitation may result in serious plugging of the flow channels, but that this can be readily controlled by pH adjustment; and that further improvement was required in the life and durability of membranes since some difficulty was experienced with membrane failure. It was evident from the field test that the membranes are a vital part of the process and hence deserved considerable study with the development of entirely new membranes needed in view of the very limited choice of these materials on the market at that time (1956). Cost estimates for the process based on the operation of the field unit are contained in the following table reproduced from the report on the field tests:

Estimated costs

Original water	Product water, parts per million	Total initial plant cost	Water costs per 1,000 gallons					Total water costs per acre-foot
			Plant investment	Operation and maintenance			Total	
				Membrane replacement	Power and other	Total		
ACTUAL FIELD EXPERIMENTAL UNIT (If operating at 25,000 gallons per day production)								
Arizona type (4,000 parts per million)	250	\$3,000	\$0.54	\$0.47	\$0.29	\$0.76	\$1.30	\$425
South Dakota type (2,000 parts per million)	250	50,400	.50	.37	.23	.60	1.10	360
PROJECTED INTERMEDIATE SIZE PLANT ¹ (Operating at 1,500,000 gallons per day production)								
Arizona type (4,000 parts per million)	500	\$1,650,000	\$0.23	\$0.30	\$0.27	\$0.57	\$0.80	\$200
South Dakota type (2,000 parts per million)	500	1,310,000	.18	.23	.19	.42	.60	197
PROJECTED LARGE PLANT ² (Operating at 75,000,000 gallons per day production)								
Arizona type (4,000 parts per million)	250	\$16,500,000	\$0.12	\$0.07	\$0.21	\$0.28	\$0.40	\$130
South Dakota type (2,000 parts per million)	250	33,800,000	.09	.05	.11	.16	.25	82

¹ Based on multiples of present stack without design changes. Progress in design improvements will lower these costs. Costs slightly higher for 250 parts per million product.

² Based on possible future development of larger stacks and other technological developments.

Present research and development work being conducted by the Office of Saline Water is concerned with two basic needs of the electrodialysis process, namely, membrane improvement and better cell designs. Since the completion of the field tests by the Office of Saline Water on the 25,000 gallons per day unit, much progress has been made by commercial firms and research organizations both in new membranes and unit designs. Much of this additional development has not yet reached commercial application.

Evaluating the characteristics of new membranes as well as new unit designs is therefore an important step in determining the areas where improvement is needed and where further research effort should be directed in order to achieve the greatest ultimate reduction in the cost of the process.

At present, the Office of Saline Water is sponsoring a general program of electrodialysis process studies at the Bureau of Reclamation Laboratories in Denver, Colo. Also, under a present contract with the Polytechnic Institute of Brooklyn, as a corollary to the work at Denver, the laboratory evaluation of various membranes is in progress and a manual of standardized procedure for testing membranes is being prepared because of the need for such procedures in a relatively new field.

The Ionics demineralizer used in the field test is currently being utilized to conduct membrane life and durability tests and to study further the hydraulic and electrical characteristics of the unit (fig. VIII).

Development of equipment for electrodialysis may be divided into two main categories; namely, the membranes themselves and the cell units which provide the hydraulic flow channels and electrical circuits for completing the assembly when membranes are added to the system. From a research standpoint, there is reason to study both membranes and cell designs independently as well as in a combined unit. In the case of membrane development, a number of commercial firms and laboratories have devoted their efforts exclusively to membrane development without reference to the cell unit in which they may be used.

An electrodialysis unit (fig. IX) has been obtained from the Central Technical Institute in the Netherlands to evaluate its performance. The Central Technical Institute—TNO—conducted extensive studies in electrodialysis for which the initial work appears to have preceded that in this country. Only recently have commercial units been made available based on the TNO work. Because of the independent development and the promise of improved cell designs on which detailed information was otherwise not available to the Office of Sa-

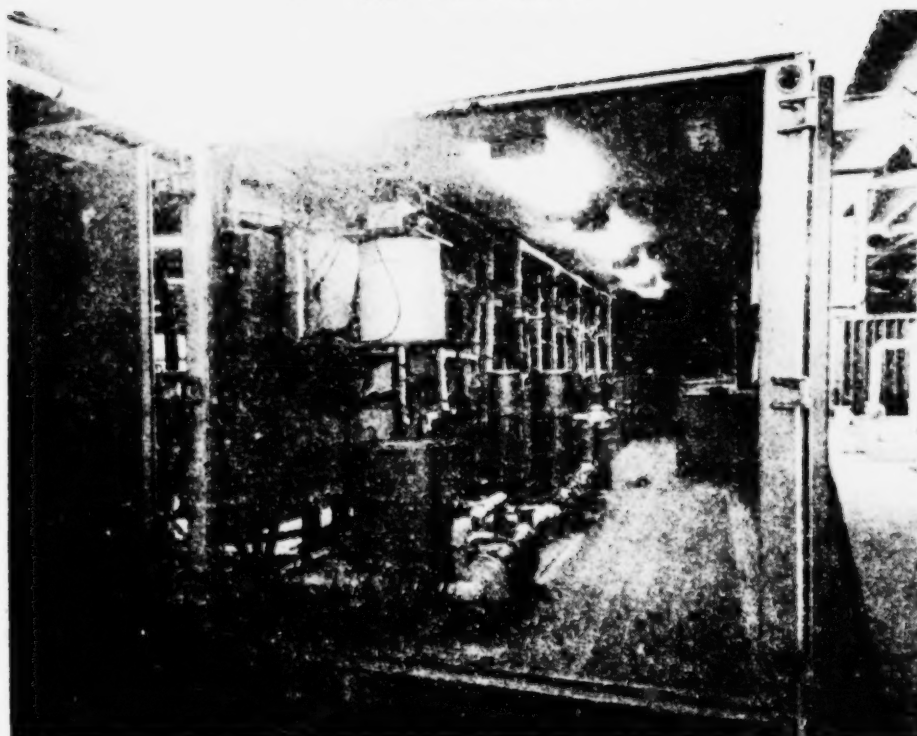
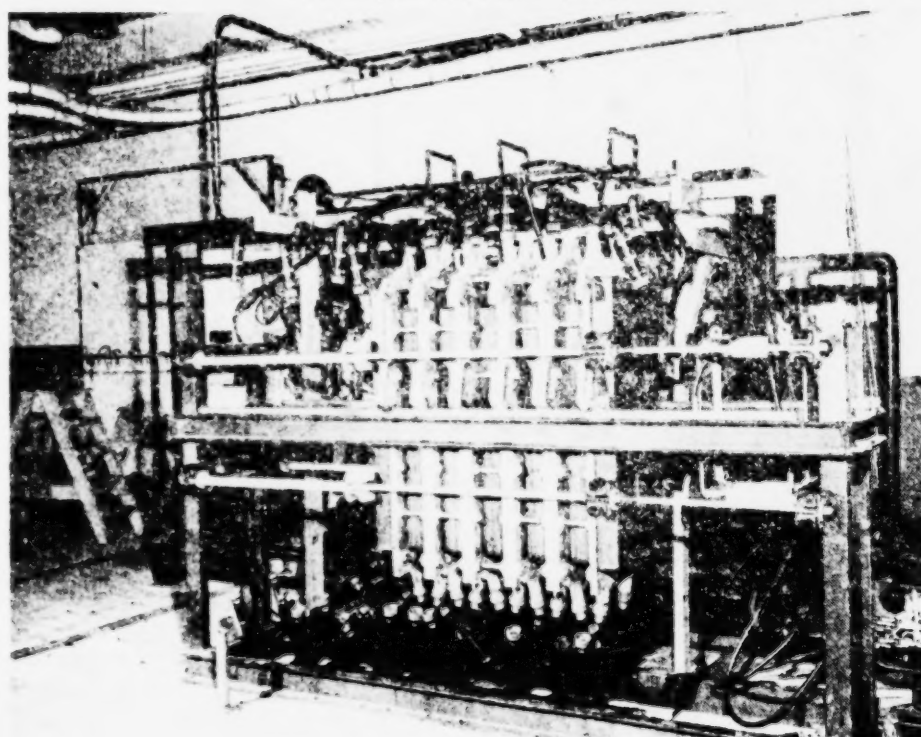


FIG. IV. TWO-FASE DESIGN



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line Water, the unit was obtained for evaluation testing at Denver to determine the technical merits of the design and its possible potential for reducing the cost of conversion. This unit has capacity of about 50,000 gallons per day when operated on water having a salinity of 2,000 parts per million. The TNO unit was also designed to utilize membranes from various suppliers which has the advantage of testing membranes which are being developed by other research organizations. Installation has only recently been completed and initial test work is now being started using commercial membranes obtained in this country.

Recently, purchase has also been made of a high-flow capacity electrodialysis stack from Ionics, Inc., for evaluation testing at Denver, to determine the improvement of the new design over earlier Ionics cells. This unit is of commercial design and consists of a single stack of 150 cells with the same membrane designs as in the previous unit, but with increased flow and higher current utilization.

In addition to the newly developed units obtained for the Denver program, units have been developed both in this country and abroad. These included a complete unit built by the Permutit Co. of New York and the Asahi Chemical Industries, Ltd., Tokyo, Japan. Also, there is the joint development of electrodialysis units by the SACSIR and the gold mining interests in South Africa.

Each of the manufacturers of the electrodialysis units has developed its own membranes. In addition, several firms have conducted development work on membranes not directly connected with a complete cell unit. These included firms such as the National Aluminate Co., American Machine & Foundry Co., and the Rohm & Haas Co. All membranes developed are of value to the electrodialysis research program, either for evaluation on a laboratory scale or for performance testing of membranes.

Improved membranes and cell designs will continue to receive primary emphasis. Specialized studies contributing to this objective are now being reviewed such as investigation of the polarization phenomena and stack designs of very large capacity for reducing costs in larger installations. Also under consideration for future work is development of methods for reducing the volume of waste brine from the process.

In addition to work sponsored directly by the Office of Saline Water, and that conducted by private commercial firms, research and development studies are also being sponsored by the Army and Navy, the Texas Electric Service Co., and the University of California. In the overseas areas, in addition to those foreign companies already mentioned, development work is being conducted by the Permutit Co. and the CSIR in England, the Asahi Glass Co. in Japan, and the Negev Institute for Arid Zone Research in Beersheba, Israel.

In the research field, new approaches such as the osmotic process, the adsorptivity of porous conductors, and the study of transport depletion are new methods for achieving salt separation by electro-ion migration which with the exception of osmionis have not yet demonstrated their practical feasibility.

SOLAR DISTILLATION

Distillation by means of solar heat has the advantage of eliminating the cost of the fuel energy otherwise required. The diffuse nature of solar energy, however, makes necessary the use of large areas for collection.

Solar distillation methods may be classified into two main groups: first, those producing steam or other heated fluid, usually by means of a focusing type collector, for use in conventional distillation equipment such as a multiple-effect evaporator unit; second, those in which absorption of the solar energy and the evaporation of water takes place in one piece of equipment, usually with self-contained condensing surface.

On the basis of several investigations it has been concluded that solar stills of simple design offer the best chances of producing fresh water from salt water at lowest overall cost. The major problems in solar distillation are reduction of equipment costs and increasing the efficiency of solar energy use. During the past year, operation of a solar research station at Daytona Beach, Fla., has begun. Prototypes of various existing and improved designs of stills are being installed and operated as a means of further development. It is anticipated that this program will produce engineering designs and specifications for practical small plants and will point the way for future solar distillation plants of larger capacity.

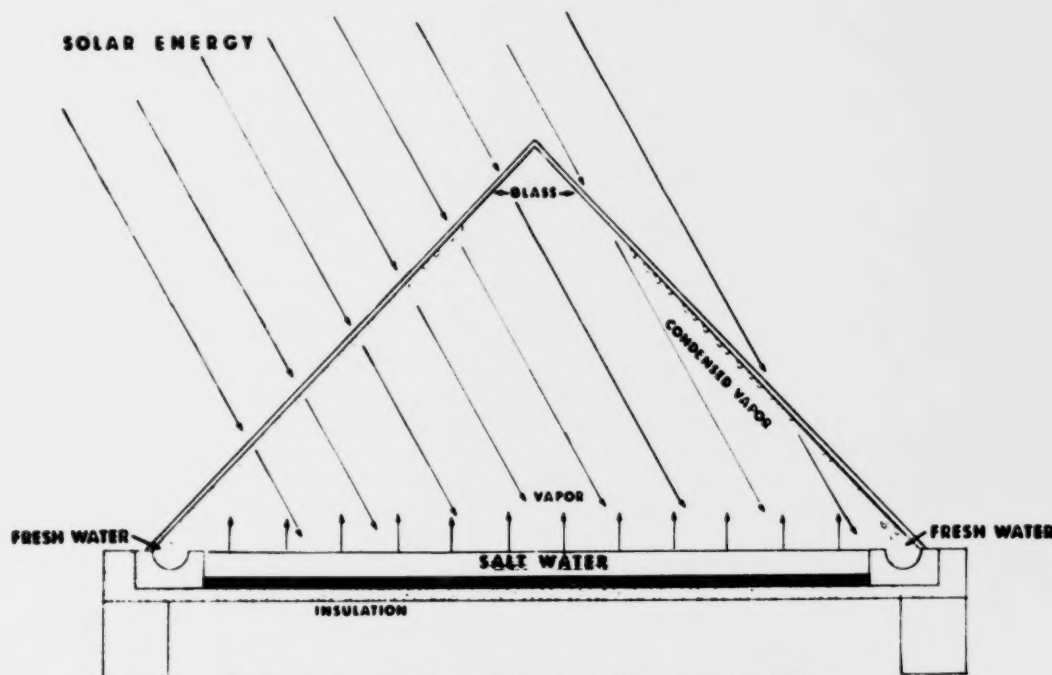
A solar still of simple design which illustrates the principles of operation is shown in figure X. This is the shallow glass-covered evaporating tray. Solar energy is absorbed on the black bottom of the tray resulting in distillation of the saline water into air space above the liquid. The vapor condenses on the sloping glass covers and distilled water runs down the inside of the glass sheets to channels at the edges of the tray.

Solar distillation processes are not yet competi-

tive in cost with other types of distillation using fuels. The most promising areas for use of solar stills are those in remote regions and in certain arid regions where solar intensities are high, conventional fuel sources scarce, and industrial development small. Numerous small units are in practical use in Algeria and Australia.

The Office of Saline Water has contracted with a number of organizations for research in this field including improving the wettability of plastic

FIGURE X.—SOLAR STILL DIAGRAM



SOLAR STILL OF SIMPLE DESIGN

films used for condensing surfaces, factors affecting the efficiency of various types of stills, and possible use of external condensers to increase yield.

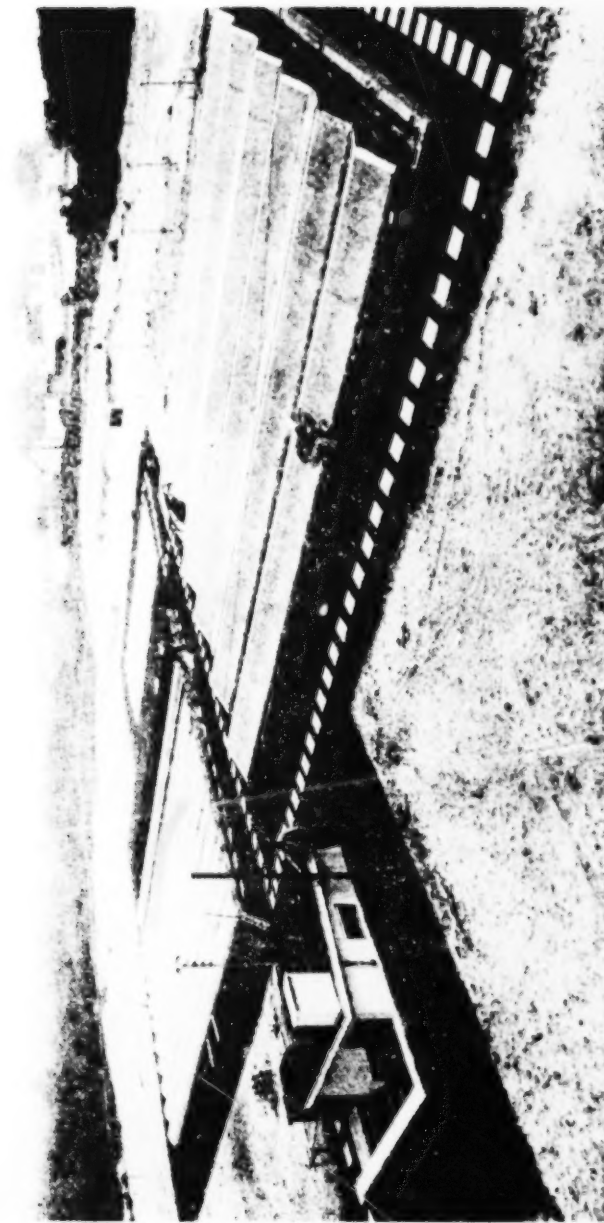
It is not expected that an optimum solar still from the point of view of economy will be developed to fit all sets of conditions. The geographical latitude, labor costs, size of still plant required, and soil and terrain characteristics all determine which of several major types of solar stills may be best suited for a given location.

A very economical approach for large-size plants in medium to low latitudes is the pond with a transparent cover. In order to secure an engi-

neering basis for design, it was considered preferable not to use natural ponds, nor even construct artificial ponds as a first step, but to design and construct a medium-size deep-basin still and to test it over a period of time under carefully controlled conditions.

A 2,500 square foot, 1 foot deep prefabricated asphaltic material basin still with 15° sloping $\frac{3}{16}$ -inch glass covers, uninsulated base, insulated concrete block sides, six sloping-bottom bays in three U-type parallel circuits was built at the Florida site (fig. XI, left) and is presently under

FIGURE XI—SHILLS AT FLORIDA STATION



test. Instruments record radiation received, heat lost to the atmosphere, production, temperature profiles in the ground under the still, and moisture content of the ground, temperatures at a great many points in the sea water evaporant, vapor-air space, the product condensate channel, and the condenser surface.

It is too early to draw final conclusions. However, initial operation shows that a production of 0.09 gallon per square foot per day has been achieved. Operating and construction experience leads us to believe that considerable design simplifications can be made without sacrificing operability. It appears that the bottom and sides can be laid by methods used in canal-liner construction.

While the deep basin solar still development does not include a radical redesign of conventional transparent covers, solar still designs by the Du Pont Co. place emphasis on the cover. In order to eliminate the handling and shipping disadvantages of glass, plastic covers have been adopted. The gable structure, and cover rigidity have been abandoned in favor of pliable-film tunnel-like shapes as shown in figure 11 (right), which are supported by means of pressure from a small electrically driven air blower. Plastics differ greatly in weather resistance (particularly under solar distillation conditions) wettability, and spectral properties. A 15-bay 2,300 square foot weatherable Mylar plastic and a 5-bay, 500 square foot Teslar plastic still have been test operated and improved for 6 months. Both plastics are Du Pont products, the latter is in experimental production, the former in commercial production. Initially a relatively elaborate design was used, mainly to prove out operability and production rates. Quite recently a highly simplified design was installed, which reduces material and installation labor requirements. Preliminary results indicate that Teslar is more durable and a better transmitter of solar energy than weatherable Mylar. However, production in the Mylar still (.08 gallon per square foot per day) has been higher because Teslar is less wettable.

Always on the search for cost-reducing concepts, this Office has given thought to the use of porous vapor transmitting, but nonwetable plastics in solar stills. A larger unit incorporating porous plastics will soon be tested in Florida.

OTHER PROCESSES

1. *Liquid-liquid extraction.*—Solvent extraction has long been recognized by chemical industry as an attractive method for effecting the separation of certain compounds and products. Its application to the desalination of water is relatively new. Basically there are two approaches to the development of a solvent extraction method for desalination, viz, the removal of salt from water and the removal of water from salt. For practical reasons, extracting water away from salt has considerably more promise. Solvents selected for this purpose must have certain general properties. First, the solvent must selectively dissolve appreciable quantities of water from the saline solution. Secondly, the solvent must form a separate phase with a reasonable temperature change, thus liberating the extracted water. Finally, the solubility of water in the solvent must be much greater than that of the solvent in water, otherwise the cost of recovering solvent would be prohibitive.

In the desalination process being developed by the Texas A. & M. Research Foundation, saline water is contacted countercurrently by the solvent which selectively extracts water at a given temperature. By increasing the temperature of the extract two phases separate: the solvent phase which is cooled and returned to the system and the water phase which is treated further to remove traces of dissolved solvent to produce potable water.

Theoretically, liquid-liquid extraction appears to be an attractive desalination process. However, the major problem in bringing the development of the process to a successful conclusion is that of finding a suitable, low-cost solvent. Efforts are presently being directed toward the search for more efficient solvents for use on brackish water rather than sea water. It is believed that the process will be more economical in the treatment of brackish water because of the lower salt and magnesium content. If the solvent extraction method can be successfully developed to desalinate brackish water of 4,000 parts per million TDS at a cost of about \$0.50 to \$0.60 per 1,000 gallons, the process would find wide application in the arid Southwest area. Future plans consider the design and construction of a small pilot plant to obtain more reliable data on the processing characteristics of the system.

PART III. DEMONSTRATION PLANT PROGRAM

In order to appreciate and understand the saline water demonstration program, one must refer to the authorizing act, Public Law 85-883, which provides "that it is in the national interest to demonstrate, with the least possible delay, in actual production tests the several optimum aspects of the construction, operation, and maintenance of sea water conversion and brackish water treatment plants" * * * and further establishes that at least three of the authorized plants shall be for sea water and are to be located respectively on the east coast, gulf coast, and west coast. Two of the three sea waterplants shall have a capacity of at least 1 million gallons per day each.

In addition, two brackish water plants are authorized to be respectively located in the northern Great Plains and in arid areas of the Southwest. One of the brackish plants shall produce at least 250,000 gallons per day of demineralized water.

Public Law 85-883 was signed by President Eisenhower on September 2, 1958, and under the terms of the act each of the first five plants is to demonstrate a different process, to be selected by the Secretary of the Interior at 3-month intervals, beginning no later than March 2, 1959, with construction to proceed as soon thereafter as possible.

With the passage of this new program, the activities of the Office of Saline Water were greatly expanded as national and worldwide interest brought an increased and continuing wave of inquiries and suggestions. Reflecting the growing national concern for additional supplies of good quality water, over 175 cities and communities have made inquiry of the Office relative to obtaining 1 of the 5 demonstration plants for their particular area. These communities are found in every coastal State (with the exception of Delaware) and cities in 11 inland States have requested consideration for a brackish waterplant.

Information covering the proposed sites and existing water problems of the various areas was needed in order to properly evaluate each application. A questionnaire was prepared and mailed to each community applicant. Information obtained in response to this questionnaire provided a basis for comparing the proposed sites. Although the Office still continues to receive occasional applications, most were received by the spring of 1959. At that time engineers of the Office of Saline Water visited virtually every proposed site in a

series of exhaustive field inspections. The State of California, acting in cooperation with the Office of Saline Water, visited proposed sites in that State—all for the purpose of confirming and obtaining additional site information. A number of communities sent delegates to Washington to explain still further their interest in obtaining one of the demonstration plants.

This all represents a remarkable interest and enthusiasm for the potentials of saline water conversion. Especially when one appreciates that the plants authorized under Public Law 85-883 will be the first of their kind, certain to be improved upon, and of only nominal sizes compared to the ultimate potentials.

While the job of obtaining site information continued, the matter of process selection moved forward concurrently. A process selection board was established in order to independently evaluate not only those processes that might be nearing the demonstration phase under the saline water research and development program, but also those suggestions that were submitted by leading industrial organizations.

The process board representing science, industry, and Government, consists of Dr. Ralph A. Morgen, president, Rose Polytechnic Institute, chairman; Dudley F. Phelps, president, the J. G. White Engineering Corp., and Capt. Ivan Monk, Head, Machinery Division, U.S. Navy, Bureau of Ships. The criteria established for process selection and the list of processes considered is attached hereto.

All available process information was analyzed and recommendations were submitted to the Secretary of the Interior. Secretary Seaton has announced three processes for demonstration plant programing and they are—

A. Long-tube vertical multiple-effect distillation (1 million gallons per day sea waterplant).

B. Multistage flash distillation (1 million gallons per day sea waterplant).

C. An electrodialysis process (250,000 gallons per day brackish waterplant).

All three of these process selections were receiving active attention under the research and development programs and each of the demonstration plants will incorporate improvements which, it is anticipated, will advance their state of technology and serve to further reduce the product water cost of the process.

Contracts for the architect-engineering services have been awarded to the following organizations:

- (a) W. L. Badger and Associates of Ann Arbor, Mich., for the long-tube vertical plant.
- (b) The Fluor Corp. of Whittier, Calif., for the multistage flash plant.
- (c) The Bureau of Reclamation, Denver, Colo., for the electrodialysis plant.

With so many communities interested in obtaining one of the five plants, selecting a specific site for each plant is a difficult task. An independent site selection board composed of three eminent engineers was appointed to assist in this matter. The board is composed of Sheppard T. Powell, chairman, Baltimore, Md., president, S. T. Powell and Associates; Lewis S. Finch, Indianapolis, Ind., vice president and chief engineer, Indianapolis Water Co.; and Dr. W. C. Schroeder, College Park, Md., consultant engineer and professor at the University of Maryland.

After careful study, the site selection board established a two-step procedure for site selection.

First, some of the proposed sites were eliminated because they failed to meet the following criteria:

- 1. Need for additional water not indicated by reason or adequacy of existing supply.
- 2. Water requirement and existing water supply system of area too small to consume water produced by conversion plant.
- 3. Saline water source seriously contaminated.
- 4. No means for disposal of brine without complicated and costly facilities.
- 5. Hazardous design and operation imposed by environmental topographical and meteorological conditions.
- 6. Prohibitive cost to reach brackish water supply.
- 7. Site does not meet Public Law 85-883 requirement.

Second, the remaining proposed sites were evaluated by a rating system which compared technical factors (62 percent) demonstration value (24 percent), and assistance offered (14 percent).

Technical factors include terrain and bearing, climate and geography, proximity to saline water, brine disposal, zoning and surroundings, adequacy and management of local water utility, power, fuel, materials and labor costs available transportation and utilities.

Demonstration factors include type and interest of area, land population and need, accessibility of site, brine utilization, and potential for expansion.

Technical and economic assistance factors include land, construction, plant operation and maintenance, sales value of converted water, and future plant purchases.

Based upon recommendations of the site selection board, the Secretary of the Interior has selected Freeport, Tex., as the site for the first sea water plant (LTV) and San Diego, Calif., for the location of the second sea water plant. Each of these sites offers a combination of physical advantages and demonstration potential considered to be better than the many other sites evaluated. Each of the communities will purchase the product water of the plant, assist in connecting with existing distribution systems.

To further support the demonstration plant program, as well as the research and development work, cooperative agreements have been entered into with the States of California, New Mexico, Arizona, Texas, and Florida. The latter four States entered into agreements since enactment of Public Law 85-883.

In a similar fashion, the Secretary of the Interior has proposed a cooperative effort with the AEC for a combination sea water conversion nuclear energy plant which would utilize heat from a process steam reactor as the energy source. As future conversion plants will need large amounts of energy, those States with limited fossil fuels (such as California and Florida) are very interested in a combination of this type. California, through its Department of Water Resources, has supported our previous studies and has voted an appropriation of \$1,500,000 as its share of the proposed converter-reactor sea water plant.

In summary, since enactment of Public Law 85-883 on September 2, 1958, the Office of Saline Water has been reorganized to handle the new workload and has—

- (1) Selected three of five processes for demonstration.
- (2) Selected sites for the first two plants and is currently evaluating location for the third plant.
- (3) Started the complete engineering designs for the first three plants with target dates for receipt of construction proposals during spring 1960.
- (4) Negotiated cooperative agreements with (a) four States, (b) the Atomic Energy Commission, (c) the city of Freeport in cooperation with the Dow Chemical Co.

PART IV. COOPERATION WITH OTHER GOVERNMENTAL AGENCIES AND INTERNATIONAL RELATIONSHIPS

Cooperation and coordination of the activities of the Office of Saline Water with other governmental agencies and foreign governments and organizations is authorized or required under various provisions of the Saline Water Act of 1952 as amended by the act of 1955, and the joint resolution, Public Law 85-883. The original act requires that the research and development activities shall be coordinated or conducted jointly with the Department of Defense, and authorizes cooperation with any Federal, State, or municipal department, agency or instrumentality, in effectuating the purpose of the act. The 1955 amendment provides that fullest cooperation shall be carried out by and with the Atomic Energy Commission and the Civil Defense Administration and further provides that not to exceed 10 percent of the funds available in any 1 year for research and development may be expended in cooperation with public or private agencies in foreign countries. Public Law 85-883 authorizes the acceptance of financial or other assistance from any State or public agency in connection with the demonstration plant program.

COOPERATION WITH FEDERAL GOVERNMENT AGENCIES

Department of Defense.—Close cooperation and coordination of activities have been carried out with the Department of Defense since the beginning of the program. Formal meetings are held periodically at which all of the work in this field of both Departments is reviewed thoroughly. In addition, informal exchange of information is carried out freely and frequently at the technical level between individuals working in both Departments. This cooperation has been exceptionally effective and has resulted in coordinated planning, elimination of duplication, and mutually beneficial exchange of technical results. At present several joint research and development projects are being planned with the Department of the Navy in cooperation with major equipment manufacturers; the Corps of Engineers, Department of the Army, have utilized the testing facilities of the Office of Saline Water near Port Orange, Fla.; and joint use of the laboratories of the Bureau of Yards and Docks, Department of the Navy, at Port Hueneme, Calif., is being explored. Records have been kept of all meetings, and technical subcommittees work out joint activities on special subjects. The re-

search and development work of both organizations has been physically inspected by the other. The Department of Defense participated in the Symposium on Saline Water Conversion held by the Department of the Interior.

Atomic Energy Commission.—Cooperation with the Atomic Energy Commission was initiated under the 1952 act and was strengthened under the 1955 amendment. An exploration study of the possible use of nuclear reactor heat in saline water distillation processes was carried out by a private industrial organization with the full cooperation from the Atomic Energy Commission. More recently, a dual purpose demonstration plant is being designed and will be constructed jointly by the Office of Saline Water and the Atomic Energy Commission. A process heat reactor of an experimental nature will be constructed by the Atomic Energy Commission and steam from that installation will be used as the energy source for a sea water distillation demonstration plant designed and constructed by the Office of Saline Water.

Office of Civil and Defense Mobilization.—Potential areas of interest have been explored each year or more frequently since 1953. It has been recognized that distillation and other saline water conversion processes are effective in removing radioactive contamination from water, and that they may be used for supplying water under emergency conditions. The two organizations, together with the Public Health Service, are giving consideration to the need for and possibility of developing special equipment which might be stockpiled by the OCDM for use in supplying drinking water to critical areas under emergency conditions.

National Science Foundation.—At the beginning of the program in 1952 a cooperative agreement was executed between the Office of Saline Water and the National Science Foundation. The agreement provides that research which is primarily of a basic nature shall be referred to the National Science Foundation, which shall have the opportunity of conducting that research, and that all research and development work proposed to the National Science Foundation having to do with saline water conversion shall be referred to the Department of the Interior. In addition, exchange and mutual use of panels of consultants is provided.

The cooperative arrangement has been effective in exchanging proposals and information between the two organizations. A number of basic research proposals have been referred to the National Science Foundation, and several development proposals have been referred by it to the Office of Saline Water. A number of consultants are used by both agencies in evaluating research proposals.

Department of Commerce.—Cooperation with the Department of Commerce has been carried out through the National Bureau of Standards, which has conducted research work on membrane improvements; the Office of Technical Services, which has assisted in the exchange of technical information, particularly from abroad; and with the Bureau of Census, which has supplied data on water uses.

Department of Agriculture.—Liaison has been maintained between the Office of Saline Water and the Department of Agriculture, principally through the Bureau of Plant Industry and Soils at Beltsville, Md., and with the U.S. Regional Salinity Laboratory at Riverside, Calif. Valuable information in the field of irrigated soils and crops has been provided by the Bureau of Plant Industry and Soils, and the Salinity Laboratory has assisted through recommendations as to type of soils and water to be considered in the planning of process developments particularly adapted to the treatment of inland brackish waters.

Department of the Interior.—The Bureau of Reclamation, Bureau of Mines, and Geological Survey have assisted the Office of Saline Water since the beginning of the program by evaluation proposals and by reviewing the program from time to time. In addition, the Bureau of Reclamation has carried out laboratory research and development on improvement of the electric membrane process (electrodialysis); has assisted in field testing of the electrodialysis process; is conducting laboratory tests of two major electrodialysis equipments; and has designed and constructed a new type rotary vapor compression distillation device particularly adapted to supplying small quantities of water for individual home use. The Bureau of Mines has proposed a number of research and development projects and at present is preparing to undertake a comprehensive program of research in corrosion and development of corrosion resistant metals needed in distillation and other conversion processes. The Geological Survey has carried out surveys of brackish water in a number of States and has made one reconnais-

sance survey of brackish water potentialities in the United States.

International Cooperation Administration.—The Office of Saline Water has worked extensively with the International Cooperation Administration since the inception of the program. In 1952 a working party was established by ICA under the auspices of the Organization for European Economic Cooperation. Several meetings were held in Europe in which the Office of Saline Water participated, and which resulted in an international cooperative research program among a number of European and other nations. That program has resulted in the development of an outstanding electrodialysis process by the Netherlands; improved solar distillation and practical commercial solar stills being used in North Africa by Algeria and Morocco in cooperation with France and other nations; and beneficial research on means of reducing scale formation and improving heat transfer characteristics in vapor compression distillation carried out by the cooperative group under the laboratories of the British Admiralty. The technical facilities of the Office of Saline Water and its consultants have been made available to the International Cooperation Administration on several occasions and proposals for installation of saline water conversion plants received by the ICA have been reviewed and evaluated by the Office of Saline Water.

Department of State.—Cooperation was established early in the program with the Department of State, and through it information has been exchanged with foreign governments and scientists throughout the world. An appropriation of \$111,111 made to the Department of State in 1957 for use of foreign currencies was used in Israel on desalting research. The Office of Saline Water reviewed the Israeli proposals and counseled with the Department of State concerning that program.

UNESCO Relations Staff provided guidance and assistance in establishing activity in saline-water conversion under the major project on arid lands.

COOPERATION WITH STATES

Under provisions of the act of 1952, as amended, formal cooperative agreements have been executed with the States of California, New Mexico, Texas, Arizona, and Florida. Except that with California this cooperation has to do primarily with the demonstration plant program. The cooperative agreement with California also includes coopera-

tion on the research and development program and that State provided approximately 40 percent of the cost of the initial research on the possible use of nuclear energy in sea-water distillation conducted under the auspices of the Office of Saline Water. Recently the State of California has appropriated \$1,600,000 to be used in cooperation with the Office of Saline Water in the design, construction, and operation of the dual-purpose nuclear heat-saline water conversion demonstration installation in California. In addition, the University of California has carried out a saline water conversion research program of its own since 1950 with which cooperation has been carried out since 1952. The work under the two research programs has been constantly coordinated, duplication has been eliminated, and the two are complementary.

COOPERATION WITH MUNICIPALITIES

In addition to the recent cooperation with towns and communities in connection with the demonstration plant program, an appreciable number of local governmental agencies have cooperated in the research and development efforts of the Office of Saline Water since the beginning of the program.

INTERNATIONAL COOPERATION

In addition to the international cooperation discussed in connection with the activities of the Department of State and the International Cooperation Administration, extensive cooperation has been carried out through the United Nations Educational, Scientific, and Cultural Organization

(UNESCO). In 1957 that division of the United Nations formed a permanent subcommittee of the major project committee on arid lands having to do with demineralization of saline waters. Through this subcommittee, UNESCO has compiled a Directory of Laboratories and Other Organizations working on developments in saline water conversion throughout the world and has obtained and disseminated information on desalting through its various news media. UNESCO held an international symposium on salinity problems in arid lands in October 1958 in cooperation with the University of Teheran. The former Director of the Office of Saline Water served as a member of that subcommittee and led the discussions at the Iran Symposium on Saline Water Conversion.

UNITED NATIONS ECONOMIC AND SOCIAL COUNCIL

The Economics Division of the United Nations Economic and Social Council has taken an interest in demineralization and in 1958 published a paper prepared by the former Director of the Office of Saline Water on the subject of the "Effects of Saline Water Conversion Present and Future on Multiple Purpose River Basin Development Planning" for that organization. In addition, the United Nations Special Fund has become interested in the activities of the Office of Saline Water and exploratory discussions are being held which it is hoped may result in active cooperation between the two organizations on such matters as preinvestment planning for saline water conversion plants in other countries.